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OUR EXPLOSIVE SUN
A Visual Feast of
Our Source of Light and Life
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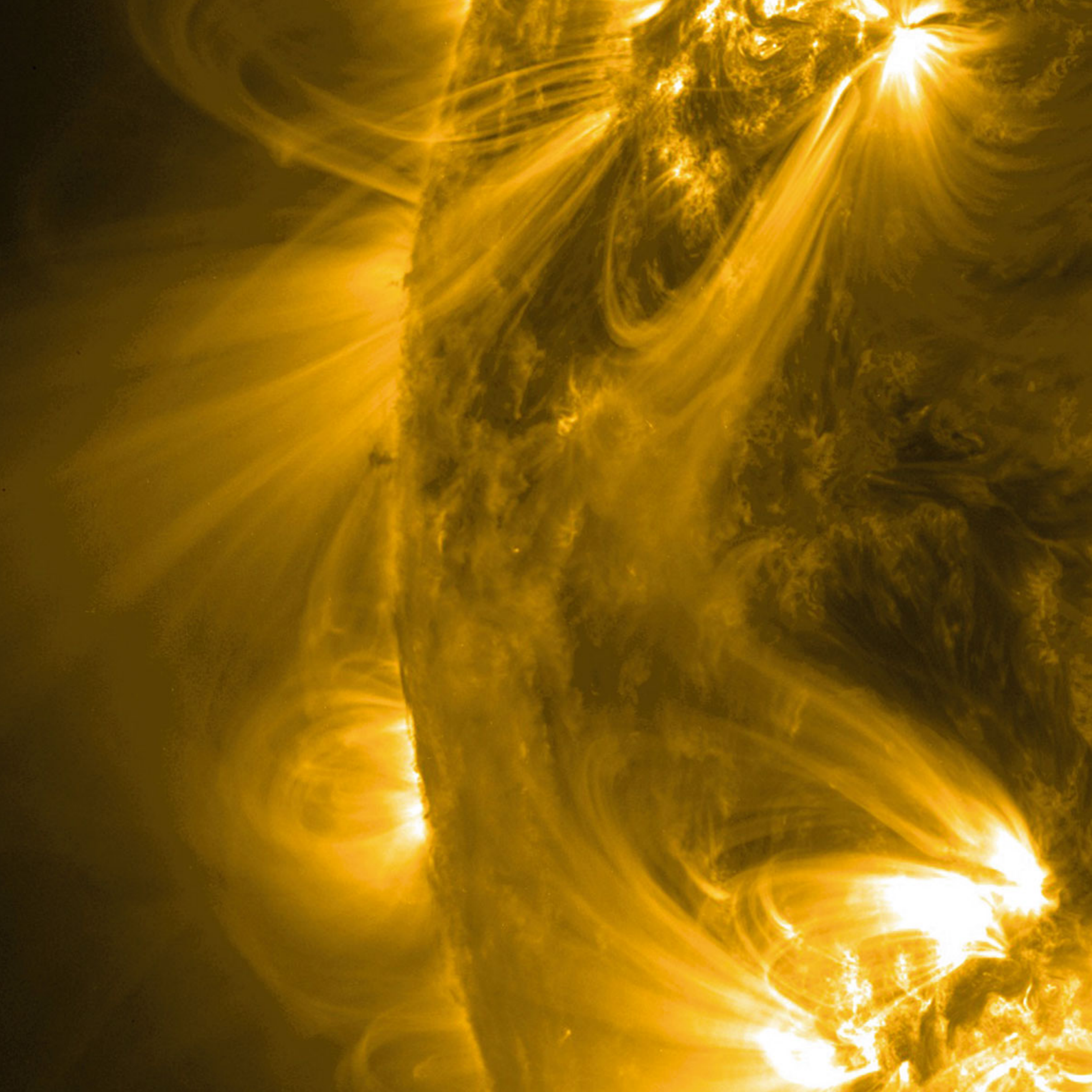

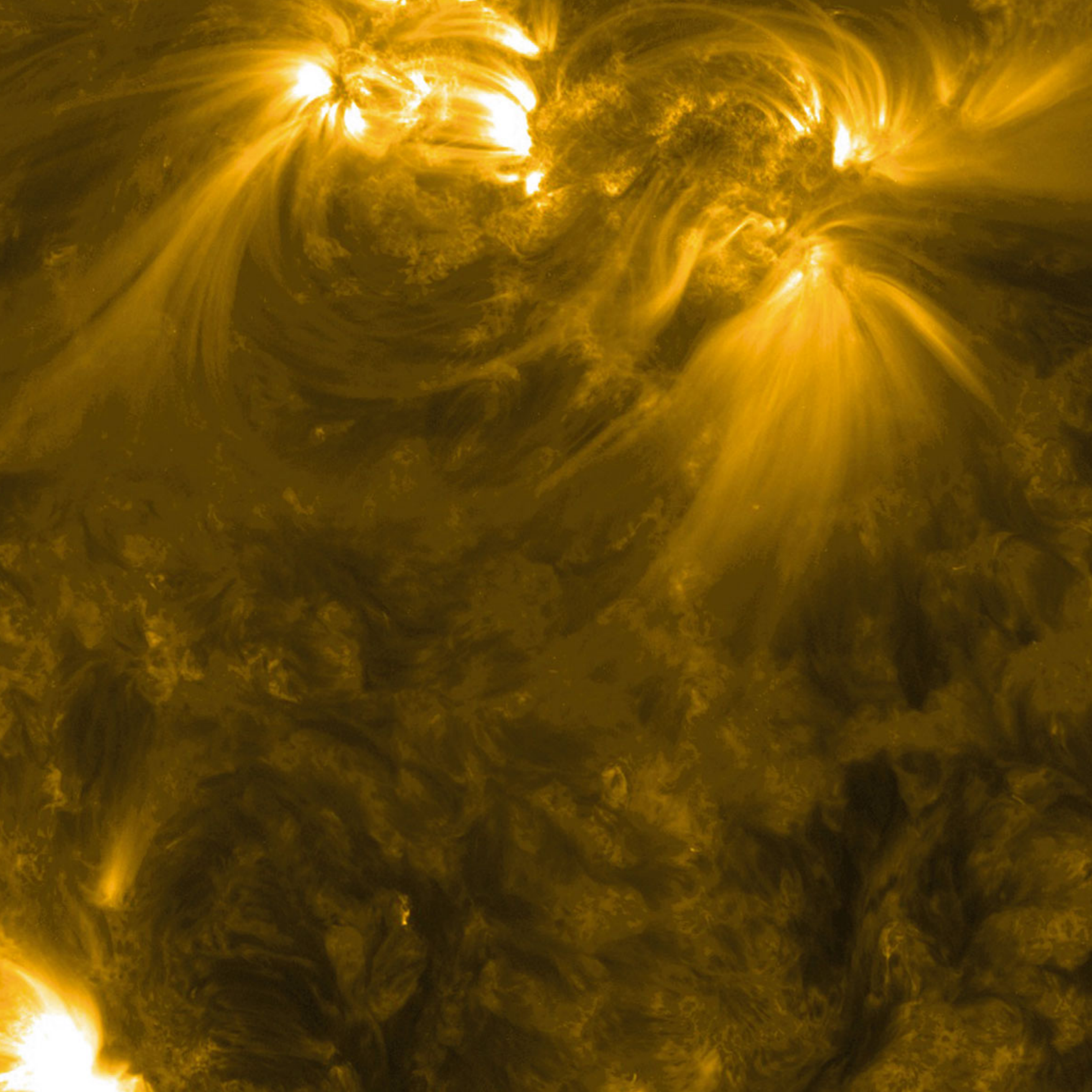

Our Explosive Sun

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OUR EXPLOSIVE

SUN

A VISUAL FEAST OF OUR SOURCE OF LIGHT AND LIFE

By Pål Brekke

Springer

The Sun and the eight planets make up our Solar System. We are just a tiny fraction of a gigantic universe (NASA).

Preface

The author took his first steps at the solar observatory at Harestua (K. Brekke).

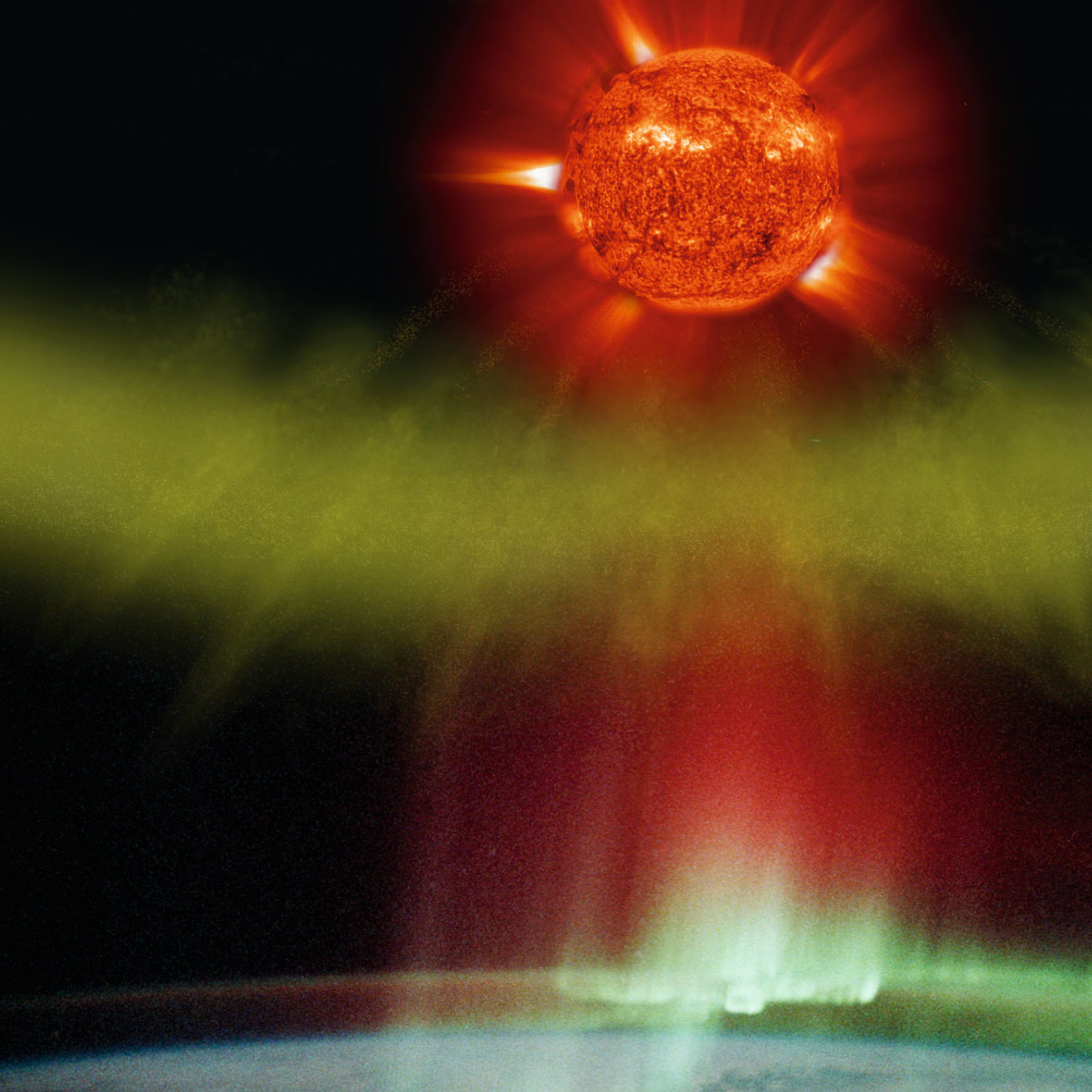
The Sun has fascinated me for many years. This is perhaps not so strange since I walked my first steps at the solar observatory at Harestua, just north of Oslo. My dad worked there then. During my studies at the University in Oslo I was introduced to Professor Olav Kjeldseth-Moe, who inspired me to do my Masters and Ph.D. thesis on the Sun. He and several of my old colleagues have been an important part of my activities as a solar physicist. They also inspired me to spend time doing public outreach. And so it was my interest for sharing knowledge about the mysteries of the Sun that led to my writing this book.

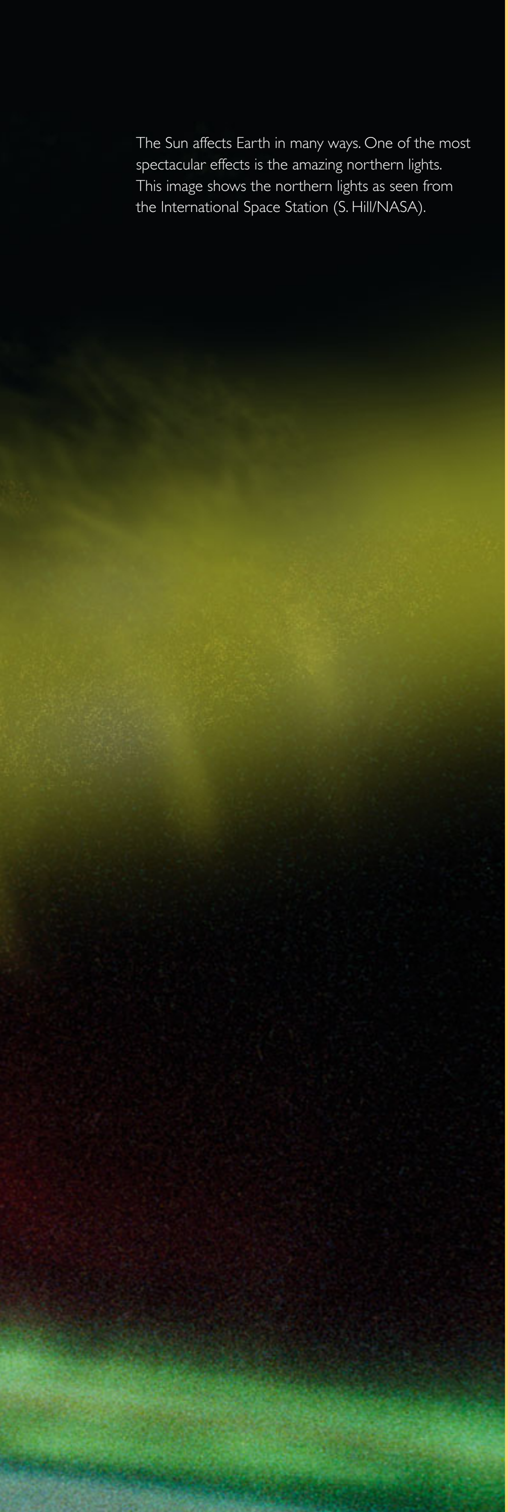
This book presents the properties of the Sun, how it has fascinated humans for thousands of years, and how it affects our technological society. My hope is that this book will inspire an increased interest in the Sun and for natural science in general. The Sun is a perfect entrance to natural science, since it affects the Earth and humans in so many ways. Solar physics interacts with many other scientific fields, such as physics, chemistry, biology, and meteorology to mention a few.

The book is paired with material on the web containing a large number of animations and video material that will provide additional information. A PowerPoint presentation of the book is also included as a useful resource for teachers.

I would like to thank everyone who has contributed to this book, in particular Andøya Rocket Range (ARR), who published the Norwegian edition. Special thanks to my colleagues Olav Kjeldseth-Moe (University of Oslo), Oddbjørn Engvold (University of Oslo), Bernhard Fleck (ESA) and in particular Steele Hill (NASA) for many useful discussions and suggestions. I would also like to thank Trond Abrahamsen (ARR) for the beautiful and original artwork.

Oslo
Pål Brekke





The Sun affects Earth in many ways. One of the most spectacular effects is the amazing northern lights. This image shows the northern lights as seen from the International Space Station (S. Hill/NASA).

Our Explosive Sun

A star among billions

When you look up at the clear night sky you can see a large number of stars. Have you at any time wondered what a star really is? Do you know that the Sun is also a star?

It can be difficult to imagine the Sun as a star, just like those we can see twinkling in the night sky. But the Sun is a star. The difference is that the stars we see at night are billions of kilometers away, while the Sun is many millions of times closer. Thus, the Sun is the only star we can study in great detail. By observing the Sun, we can also learn about other stars.

For thousands of years humans have gazed at the night sky and wondered about the universe. They did not know that the stars were so much like our own Sun, that we are part of a large galaxy, that there are billions of other galaxies, and that we are just a short moment of the 13.7-billion-year history of the universe.

If we had to rely on only our own eyes we would not have any possibility of discovering other galaxies and solar systems. Today giant telescopes on the ground and in space help us to explore the universe. If the telescope were still not invented, only six planets, the Sun, our Moon, and a few thousand stars would be known to us.

The Milky Way and Comet McNaught seen over the mountains in Argentina. (M. Druckmuller).

Everyone can see the Sun, but you cannot, and should not, stare at. It is so bright that it will damage your eyes if you try.

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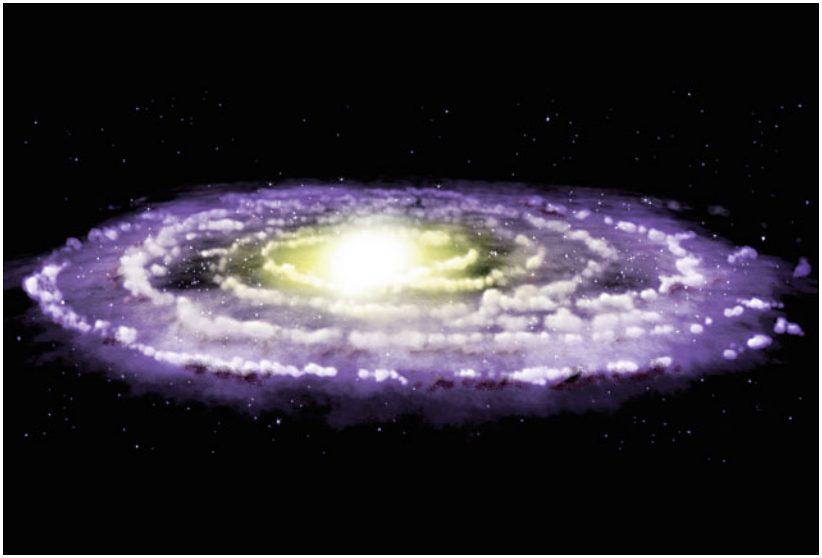
By using very long exposure times one can take pictures of the stars' movements in the night sky. Here the stars as seen from the Gemini Observatory in Chile. (Gemini Observatory/ P. Michaud).

The milky way: Our neighborhood

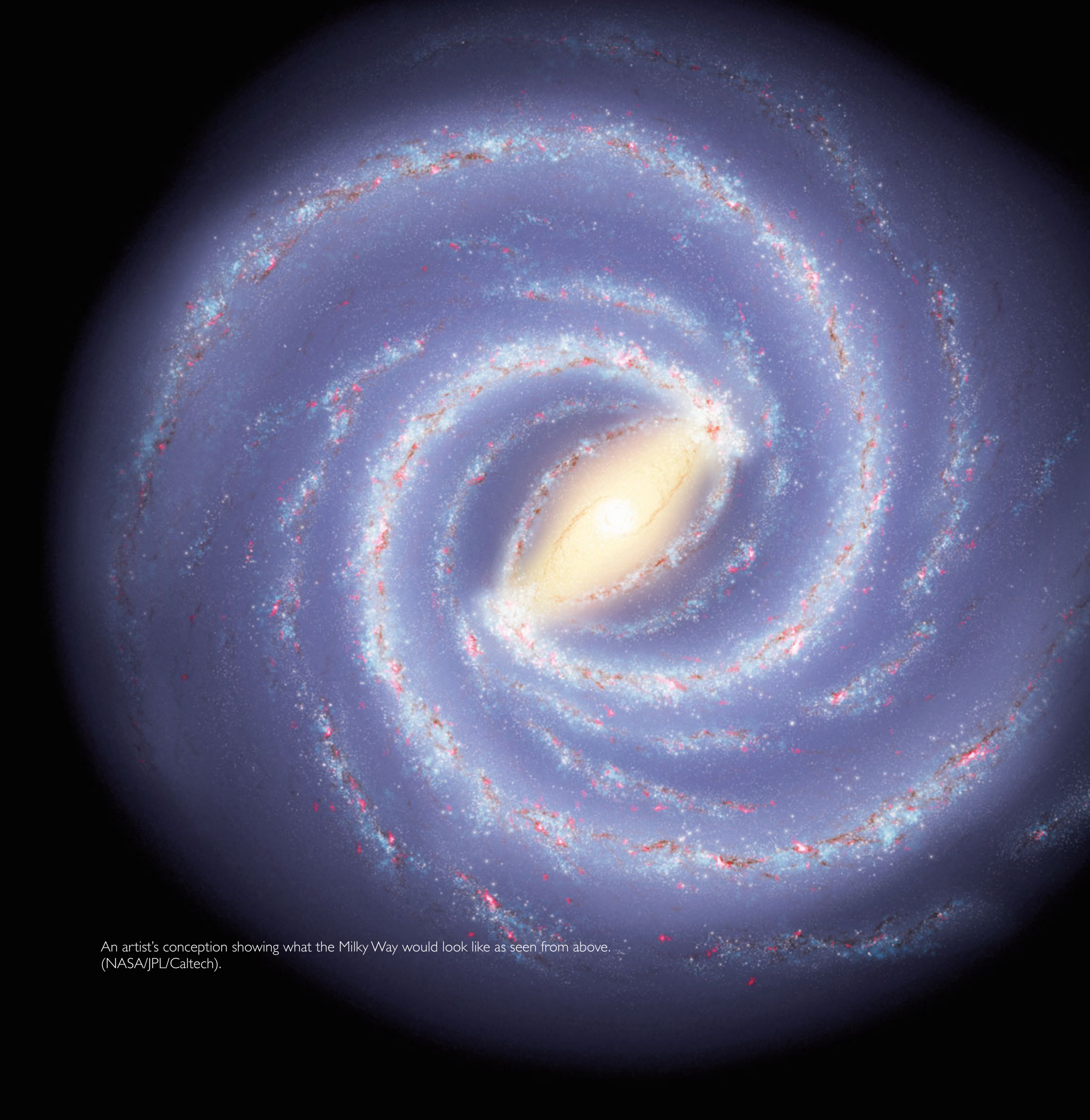
All stars that can be seen with the naked eye belong to our galaxy – the Milky Way. The Milky Way is so big that light spends hundred thousand years traveling across it. Our Solar System is located in one of the spiral arms in the Milky Way. We are one of more than 200 billion other stars in the galaxy. Including billions of other galaxies the number of stars in the universe is almost unthinkable. Some scientists have still tried to find out and estimated about 300,000,000,000,000,000,000,000,000 (300,000 billion billion) stars. This number is about 3,000 times bigger than the total number of sand grains on Earth (including all beaches and deserts). Even though about 5,000–8,000 stars are visible from Earth with the naked eye, a human can only see about 2,500 stars from any given location.



The Milky Way – our home in the universe. (NASA/CXC/M.Weiss).

FUN FACT: If you tried to count all the stars in our galaxy, and you count one star per second, it would take you close to 3,000 years to finish. (It would be really irritating to lose count, though, after 50 years!)

FUN FACT: The Sun, together with the planets, is racing around in the Milky Way at a speed of 250 km/s, or 900,000 km/h. Even with this amazing speed it takes us 240 million years to make one round.



An artist's conception showing what the Milky Way would look like as seen from above. (NASA/JPL/Caltech).

Distances in space

The distance to the stars and other objects in the universe is unbelievably big. Thus, it is not practical to use kilometers or miles as a measure. Instead, astronomers are using “light years” as a unit for distances in space.

A light year is the distance the light travels in 1 year. The light is moving very fast – almost 300,000 km per second! This is over one billion km/h. You could travel between London and New York 20 times in 1 s if you could travel that fast.

So – how many kilometers is a light year? The speed of light is 299,792 km/s. The calculation is then: 299,972 × 60 s × 60 min × 24 h × 365 days = approximately 9,460,000,000,000 km or 9,460 billion km. Almost an unbelievably large number.

When we are measuring distances in space a yardstick is not very useful. (T. Abrahamsen/ARS).

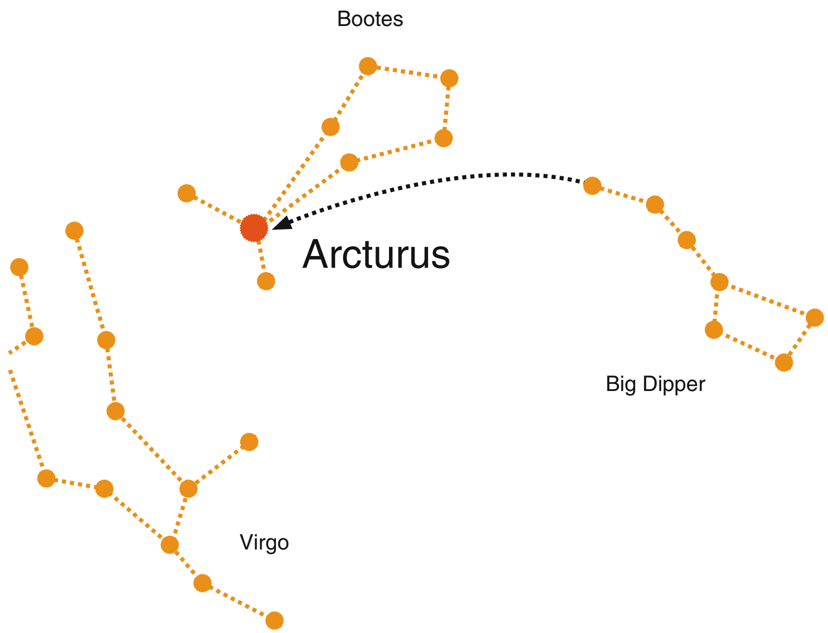
A large number of galaxies with different shapes have been observed with the Hubble Space Telescope. The distance to these galaxies is about 13 billion light years. (NASA).

The light from a star that exploded 5 years ago is continuing to move out through a cloud of surrounding gas. The light reflected by the gas makes it visible to us. (NASA).

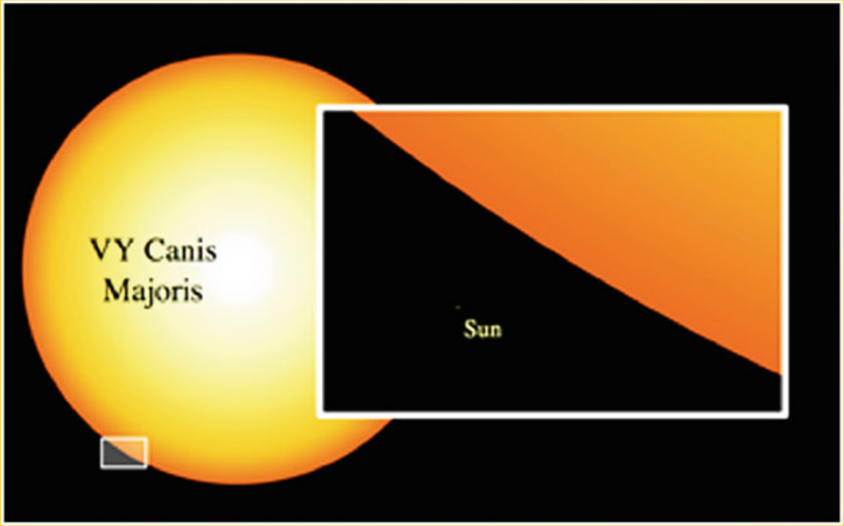
The sun in relation to other stars

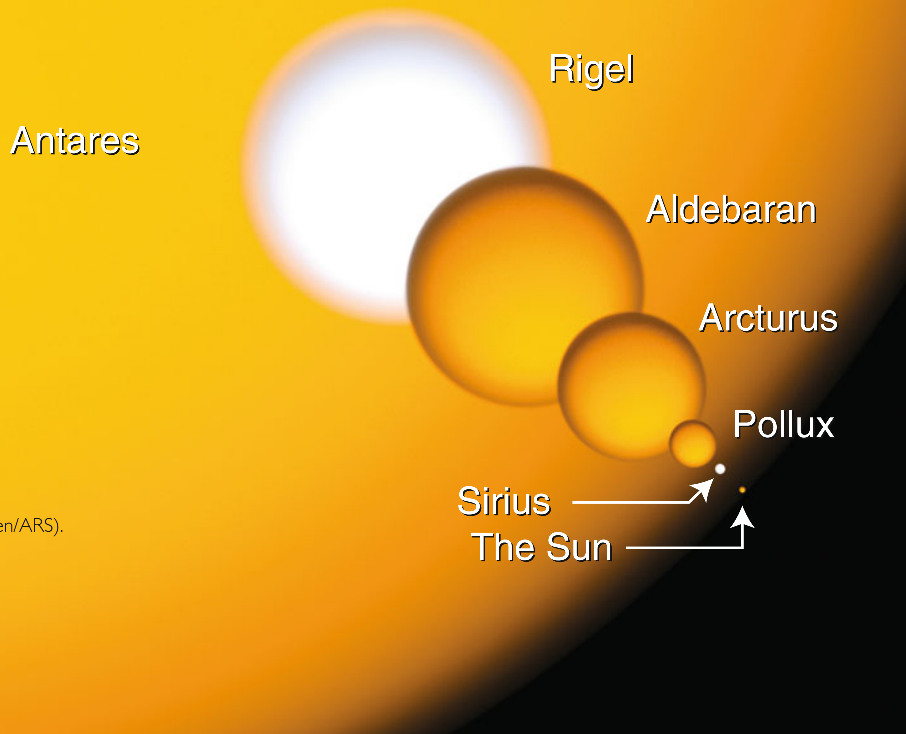
The sun is a quite modest star. Other stars are up to 2,000 times bigger. Others are 100 times smaller. The star Arcturus has a diameter 25 times that of the Sun. We do not notice its size, since it is located 37 light years out in space. It is however easy to find if you can locate the Big Dipper constellation. Just follow the direction of the handle until you see a bright star.

Aldebaran's diameter is 44 times that of the Sun and is 64 light years away. Antares is 480 times bigger, but is located about 600 light years away. The biggest known star is VY Canis Majoris and is about 2,000 times bigger than the Sun. It is located 4,900 light years away.



The star Arcturus is easy to find if you follow the handle on the Big Dipper. (T. Abrahamsen/ARS).





The Sun compared to some of the giant stars (T. Abrahamsen/ARS).

Our closest neighbor stars

Our closest neighbor stars are Proxima Centauri and Alpha Centauri A and B. They are part of a triple star system.

The small star Proxima Centauri has a surface temperature of only 2,400°K and shines 13,000 times dimmer than the Sun. It is one of the dimmest known stars. Alpha Centauri A, however, is about the same size as the Sun.

Proxima Centauri is located 4.22 light years from the Sun. This corresponds to 39,924,576,000,000 km, or 39,924 billion km! Thus, the light we observe from it today is over 4 years old.

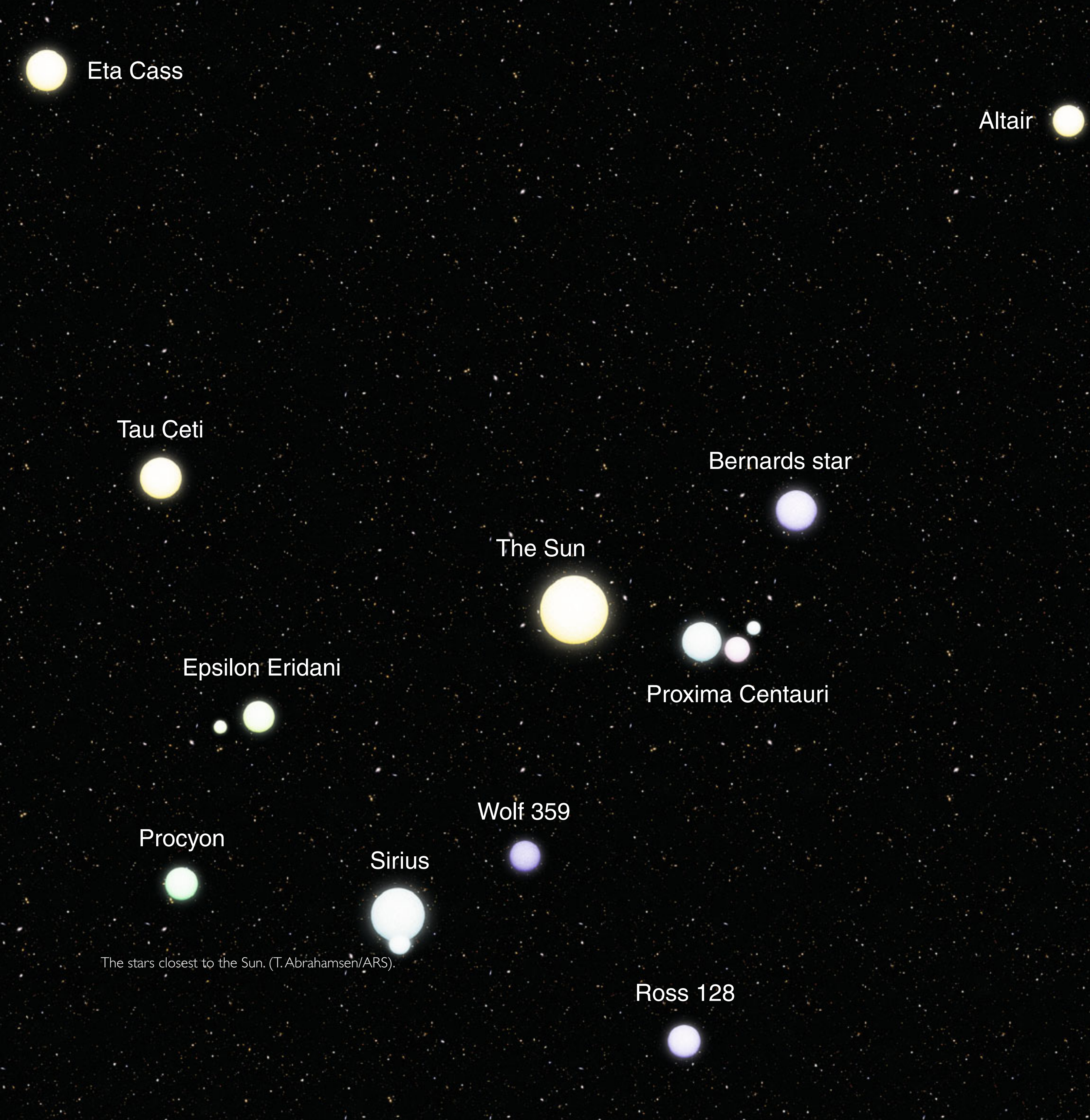
Imagine you wanted to travel to this star. Would that be possible? Check out the fact box.

Our closest galaxy, Andromeda, is about 2.5 million light years away. The light we see today from Andromeda started its journey toward us 2.5 million years ago. Thus, we see 2.5 million years back in time.

Alpha Centauri A and B are the two bright stars in the picture, while Proxima Centauri is so dim that it is hard to spot. (M. Lorenzi).

FUN FACT: If you could drive a car at a speed of 100 km/h, it would take 47 million years before you arrived at Proxima Centauri.
By comparison it would only take about 170 years to get to the Sun.

FUN FACT: If you could borrow the space shuttle, which typically travels at a velocity of 27,600 km/h, it would still take you about 168,000 years to get to Proxima Centauri.



The stars closest to the Sun. (T. Abrahamsen/ARS).

Other known stars

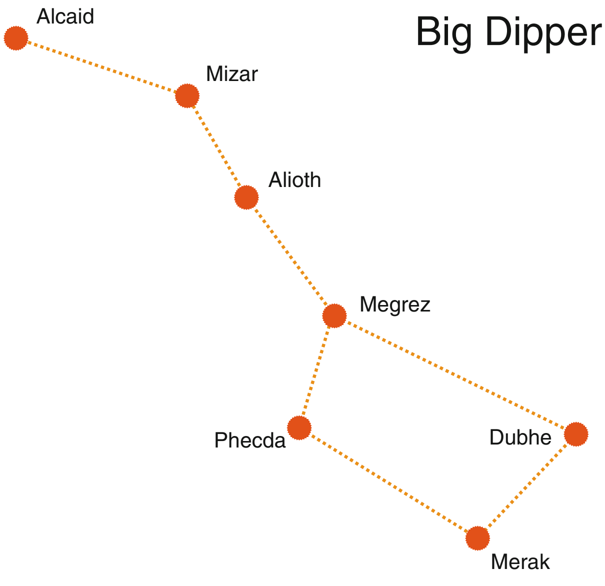
The Big Dipper is probably the most well known constellation. It is part of the bigger constellation Big Bear. Even if the stars in a constellation appear to be located close to each other they can be many light years apart. The last star in the handle of the Big Dipper is Alcaid and is located 210 light years from the Sun. The next star, Mizar, is only 88 light years away. The distance between them is 122 light years, which means more than 100 trillion kilometers. The strongest star is Dubhne, a yellow supergiant shining 145 times brighter than the Sun and is 100 light years away.

The brightest star in the well-known constellation Orion is Rigel and is located about 900 light years away. It shines 60,000 times brighter than the Sun, so we should be happy we are not too close. The red-yellowish star in the upper left is Betelgeuse, a red supergiant 518 light years away. It is so big that if it happened to be our Sun it would have swallowed both Earth and Mars.

The Pleiades is an open star cluster and easy to find on the night sky. The stars are located 440 light years away and were studied by Galileo some 400 years ago when he pointed his telescope toward the night sky.

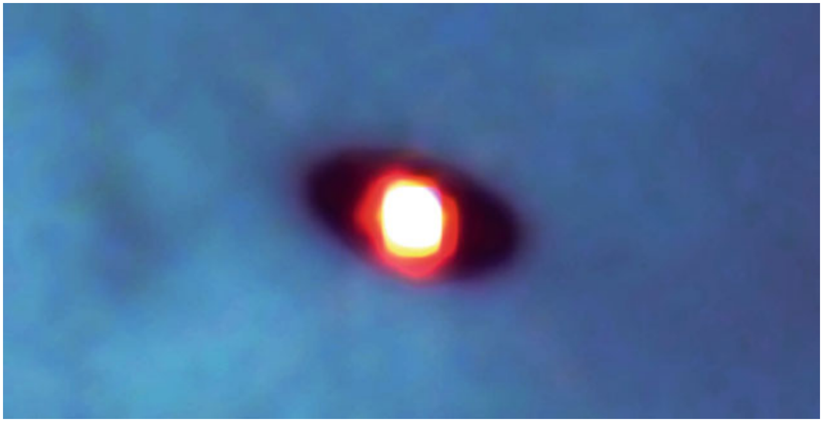
Here is an amusing thought: If, in 40 years time, you lived on a planet around one of these stars and had a super telescope, you would be able to see something amazing. If you pointed your telescope toward Earth, you would actually see Galileo staring at you. Since the light was taking 440 years to travel between Earth and the Pleiades, you would be looking 440 years back in time.

The Pleiades is an easily visible open stellar cluster with beautiful dust clouds. The stars are about 440 light years from the Sun. (M. Fjørtoft).



The Big Dipper is maybe the most well known constellation on the northern hemisphere. (T. Abrahamsen/ARS).

The constellation Orion consists of stars with different colors. The red giant Betelgeuse is seen in the upper left, and the clear blue Rigel is in the lower right. (M. Fjørtoft).



A newborn star in the Orion Nebula, still with a disk of dust and gas surrounding it. Soon planets may form out of the contracting gas. (M.J. McCaughrean (MPIA), C.R. O'Dell (Rice), NASA/ESA).

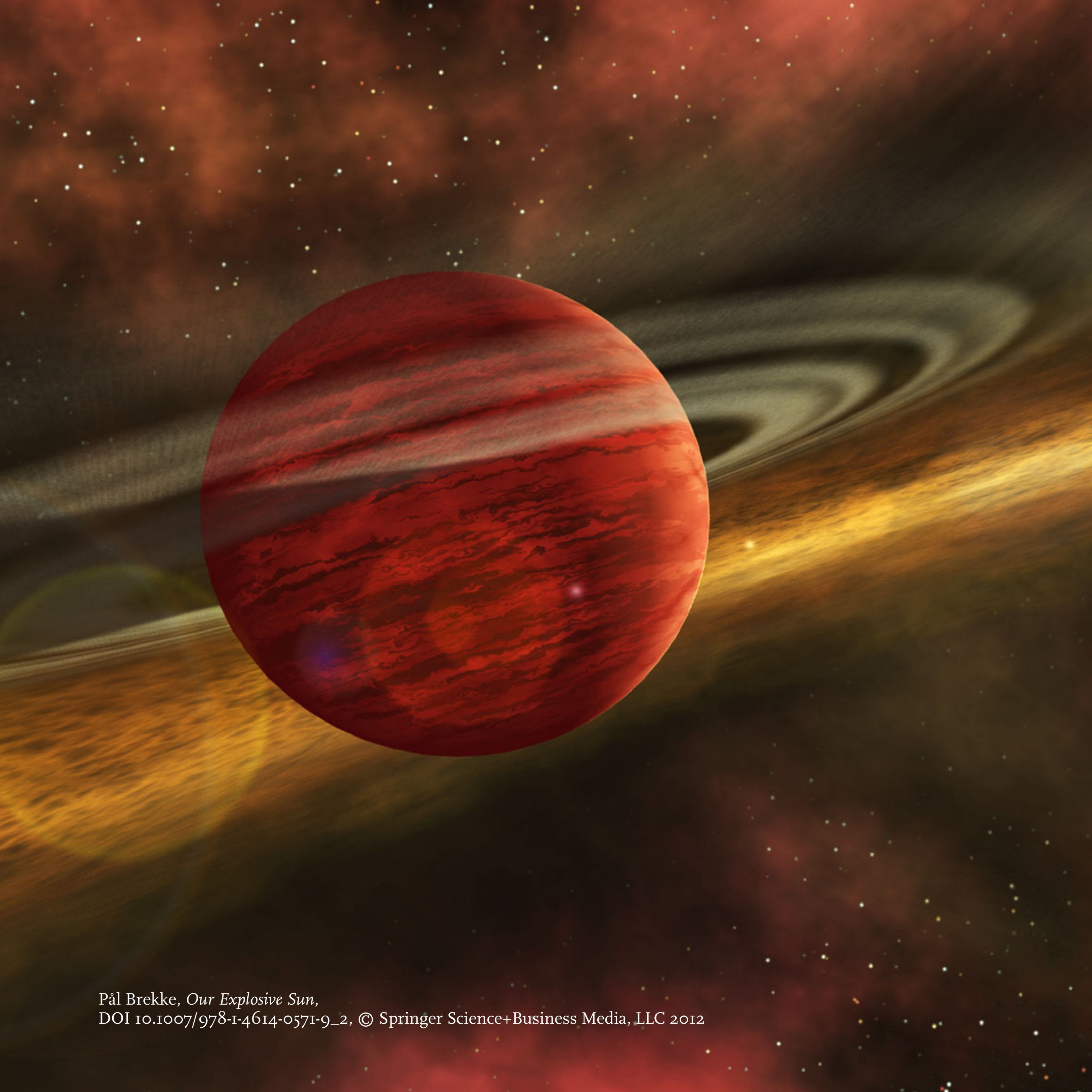
Stellar nurseries

Stars are born and die in space all the time. In space there are large areas with clouds of gas and dust, which we call stellar nebulae. A star is born when a cold cloud of gas and dust contracts. At some point the central region gets so dense and hot that nuclear reactions ignite and the star "turns on." Sometimes planets are formed out of the remaining gas and dust around the newborn star.

The images here show examples of such nebulae, which we often call stellar nurseries. It is hard to grasp the dimension in such images. In the picture on the left the pillar of gas is almost 10 light years tall – more than double the distance between the Sun and our closest star, Proxima Centauri.

The spooky-looking Eagle Nebula is a giant stellar nursery where new stars are born. (NASA).

In the Eagle Nebula we can see what scientists call stellar "eggs," where gas has started to contract to form new stars. (NASA).



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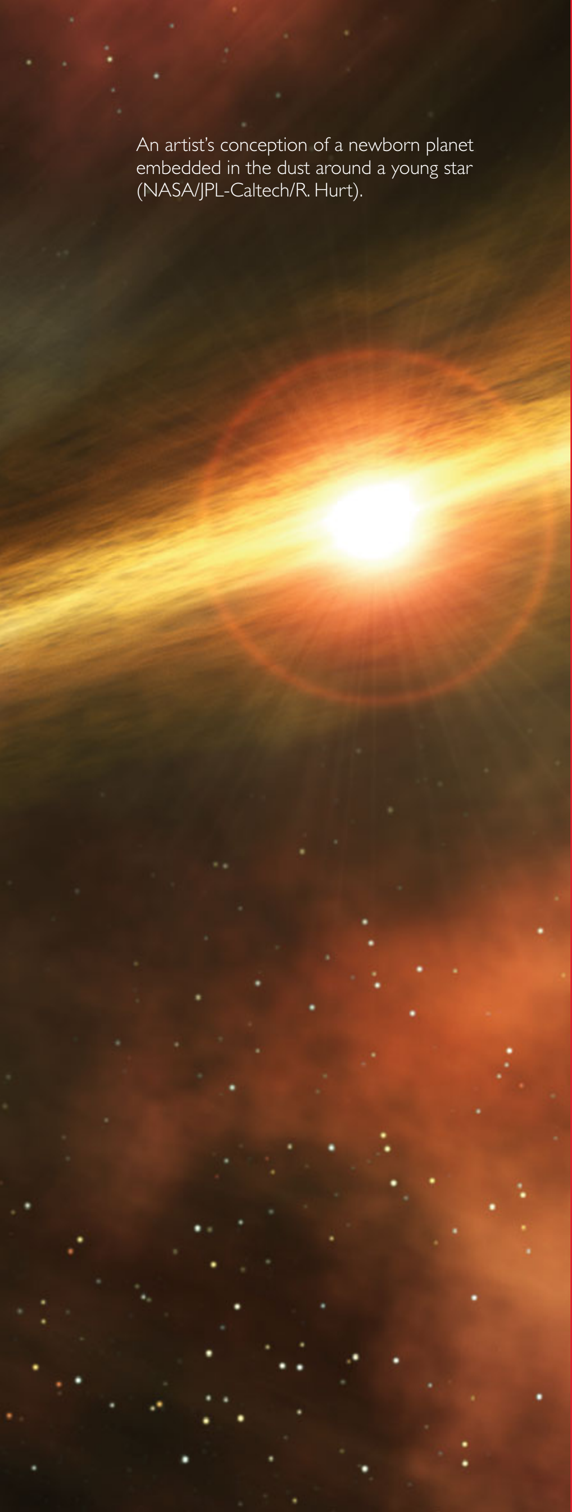


An artist's conception of a newborn planet embedded in the dust around a young star (NASA/JPL-Caltech/R. Hurt).

THE SUN'S PLACE IN THE SOLAR SYSTEM

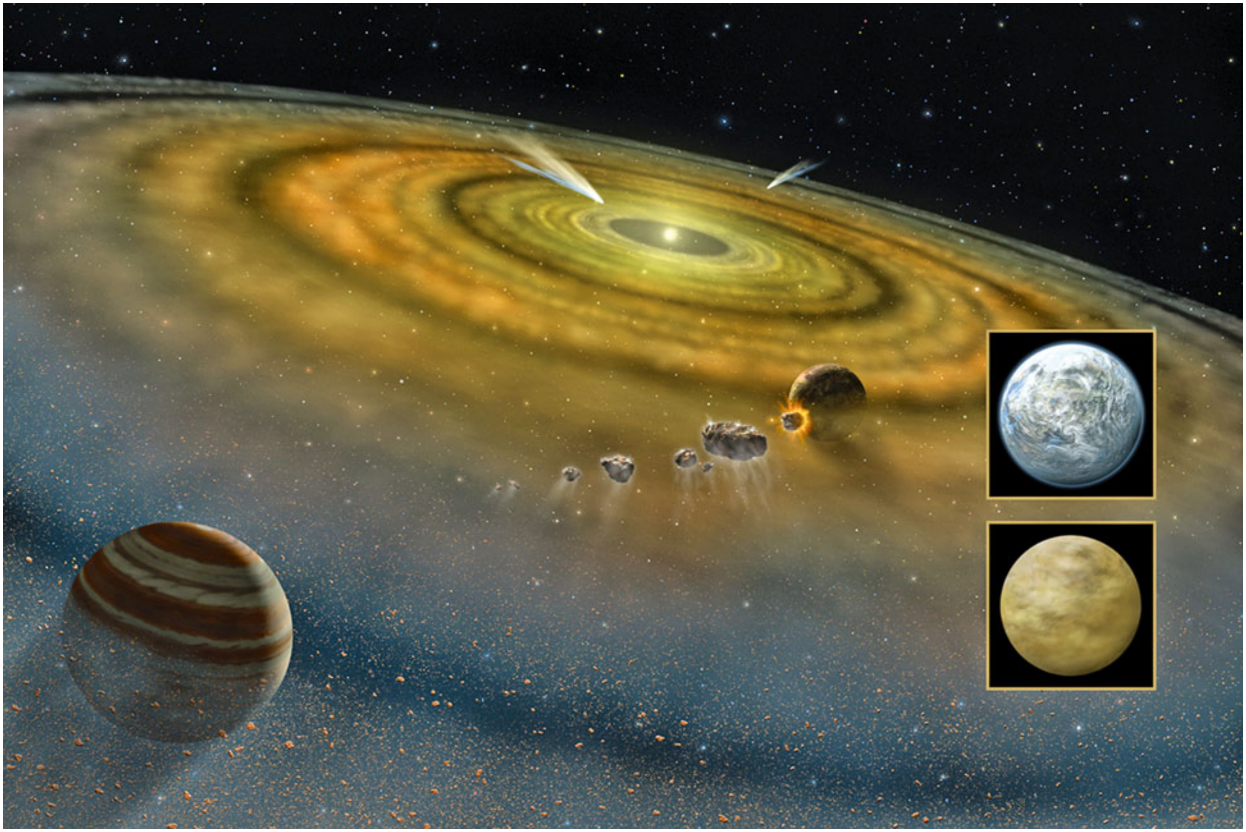
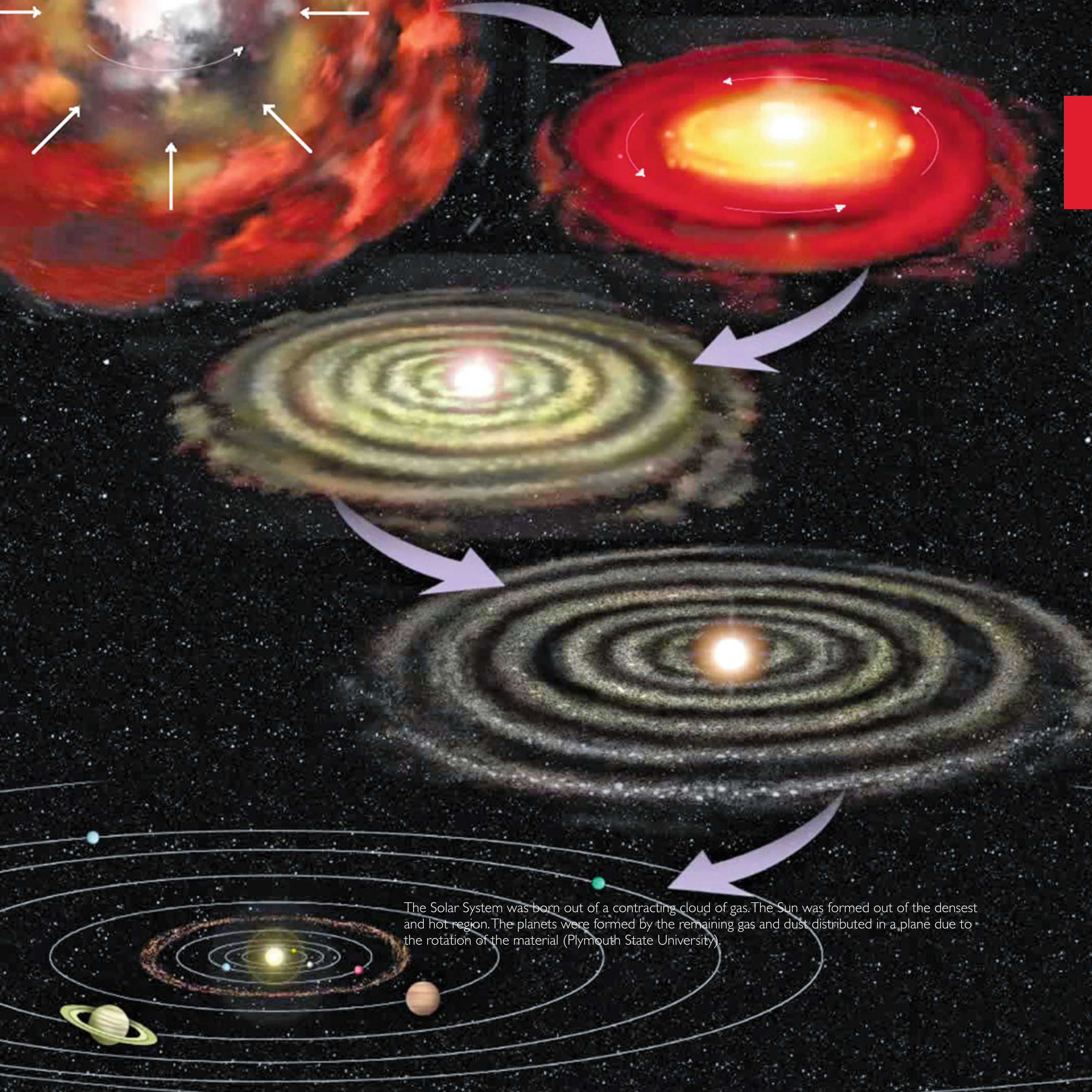


Illustration showing what our newborn Solar System might have looked like (NASA/FUSE/Lynette Cook).

Our Solar System Is Born

The Solar System was born about 4.5 billion years ago. Astronomers believe the Sun and the planets were created from a collapsing cloud of dust and gas. An exploding star, likely a nearby supernova, made the cloud of gas contract. As the gas contracted more and more due to increased gravitational forces, it got warmer. At some point, nuclear reactions ignited in the central part and a new star was born. Further away from the star, gas and dust were also collapsing, and these smaller clumps later became the planets, moons, comets, and asteroids.

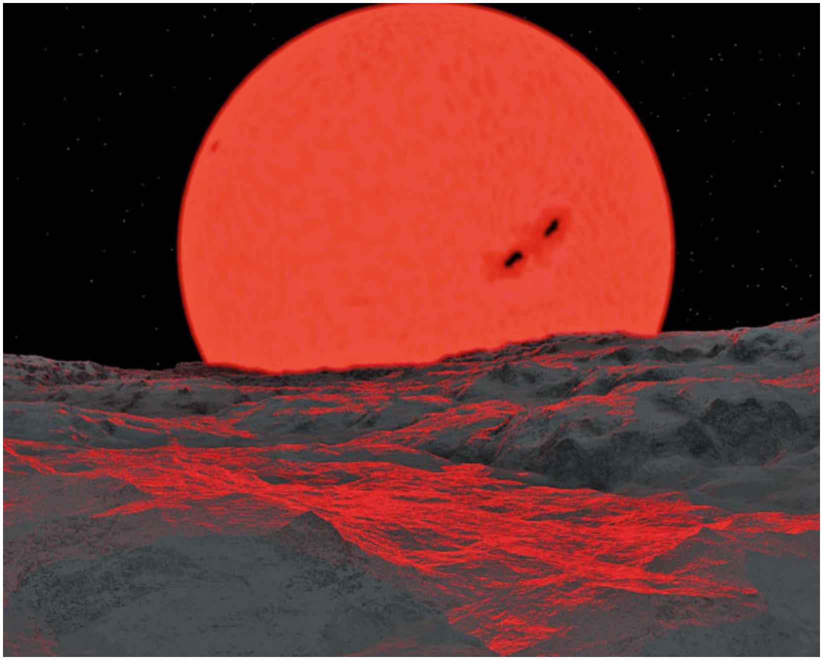


The Solar System was born out of a contracting cloud of gas. The Sun was formed out of the densest and hot region. The planets were formed by the remaining gas and dust distributed in a plane due to the rotation of the material (Plymouth State University).

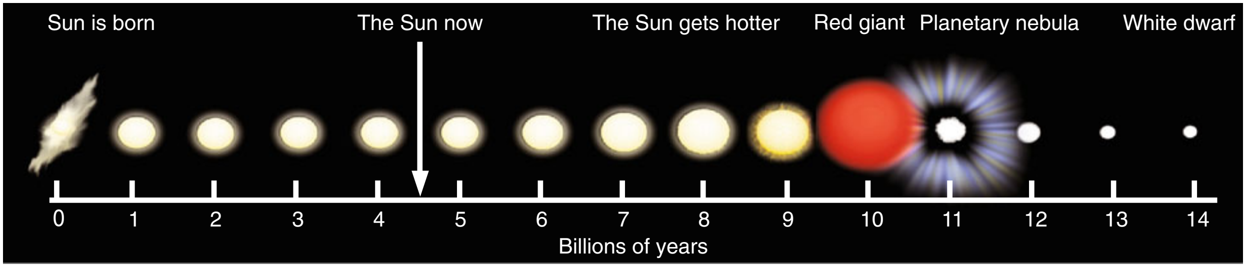
The Life Span of the Sun

The Sun is 4.5 billion years old and born out of a cloud of gas. The cloud contracted, and when the pressure and temperature in the central part got high enough, the nuclear reactions started and the Sun was born.

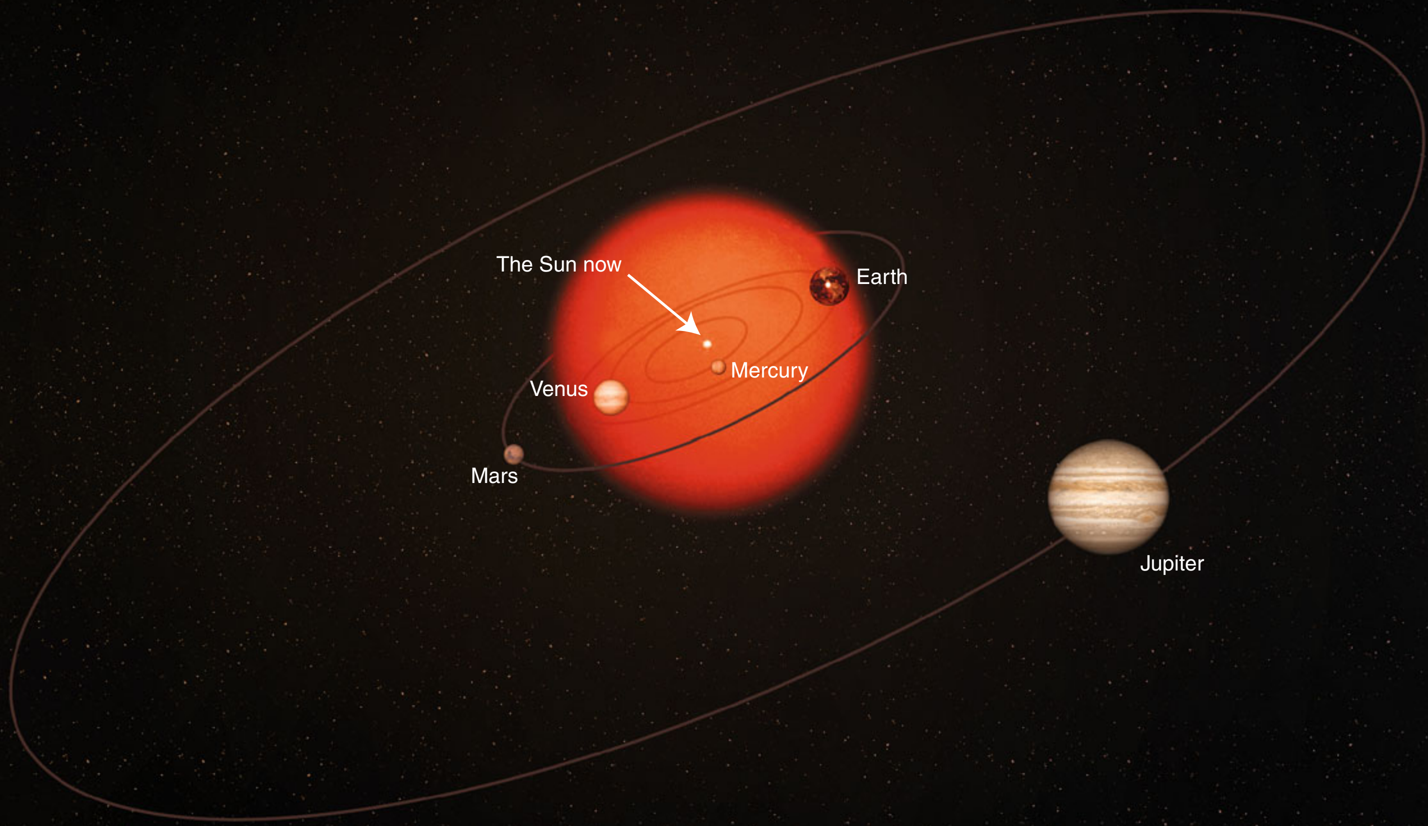
In the next 5 billion years, more and more of the "fuel" hydrogen will be converted to helium, and the temperature of the Sun will increase. When all the hydrogen is spent, the Sun will expand to a red giant and swallow Mercury, Venus, and maybe also Earth. It will be 250 times bigger than today. Then the Sun will eject its outer layers and lose mass. The ejected gas will form a planetary nebula around the remaining hot core, which will then be called a white dwarf. It will be just the size of Earth and will slowly cool down and eventually fade out over the following billion years. This is a typical lifespan for relatively small stars such as the Sun.



Artist's concept of what we think a rapidly growing Sun would look like from an already extinct Earth (J. Bryant).



The life cycle of the Sun through 14 billion years (T. Abrahamsen/ARS).



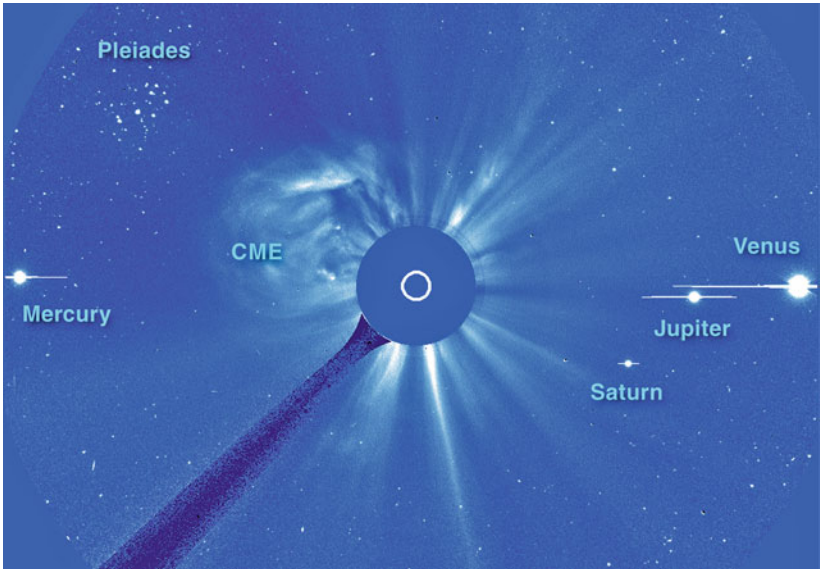
The Sun will expand and swallow Mercury, Venus, and maybe also Earth in about 5 billion years (T. Abrahamsen/ARS).

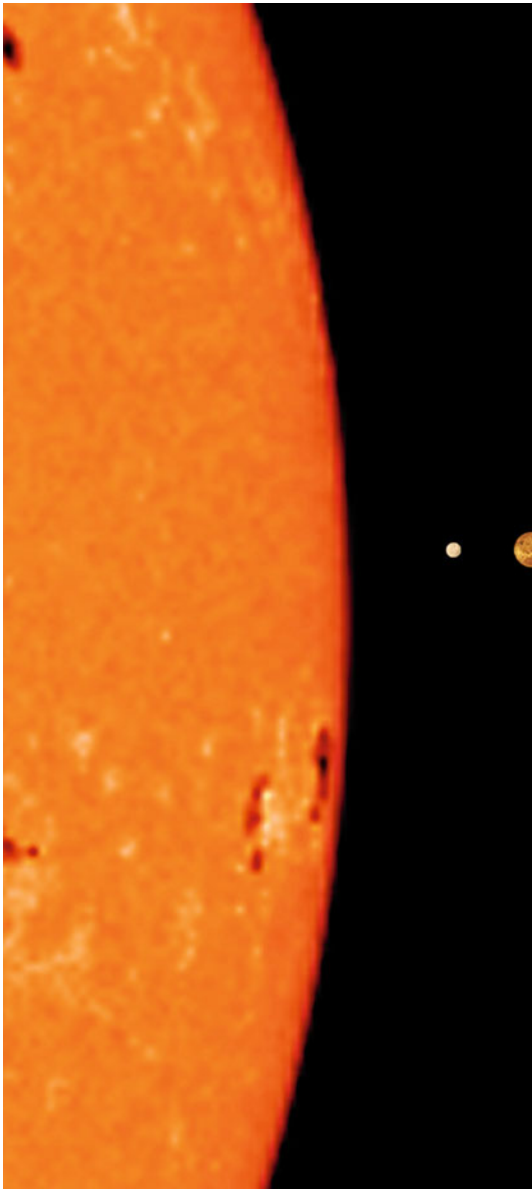
The Solar System

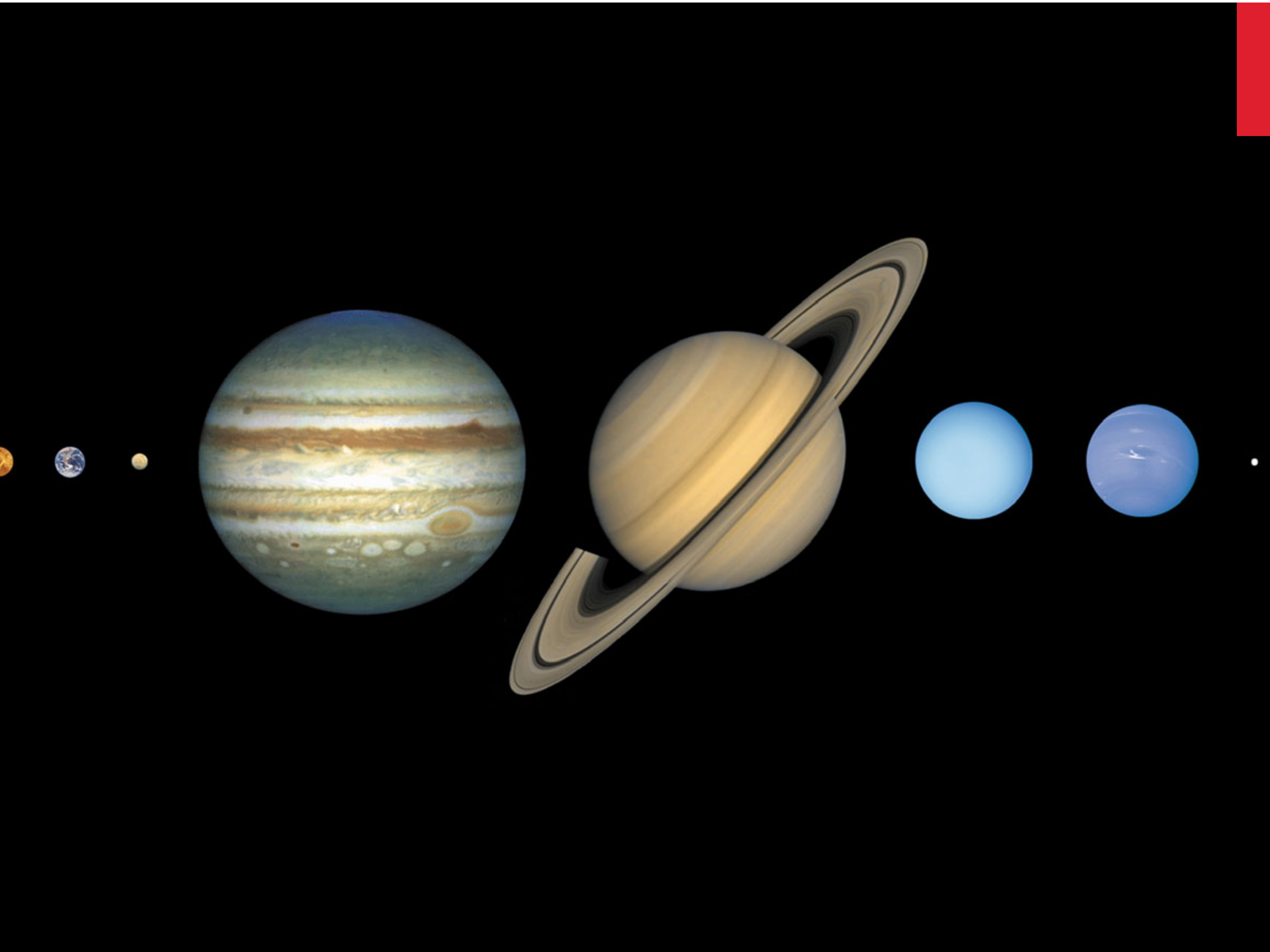
The Sun is the center of the Solar System and also the largest object, containing more than 99.8% of the total mass of the Solar System. The eight planets rotate around the Sun in separate orbits, kept in place by gravitational forces from the Sun. In addition, there are billions of other objects orbiting such as asteroids, comets, moons, and dwarf planets.

The four inner planets – Mercury, Venus, Earth, and Mars – are called the rocky planets and are all relatively small. Further out are the big gaseous planets – Jupiter, Saturn, Uranus, and Neptune. Outside Neptune is the small and strange dwarf planet Pluto. Pluto was earlier regarded as a planet but was reclassified as a dwarf planet.

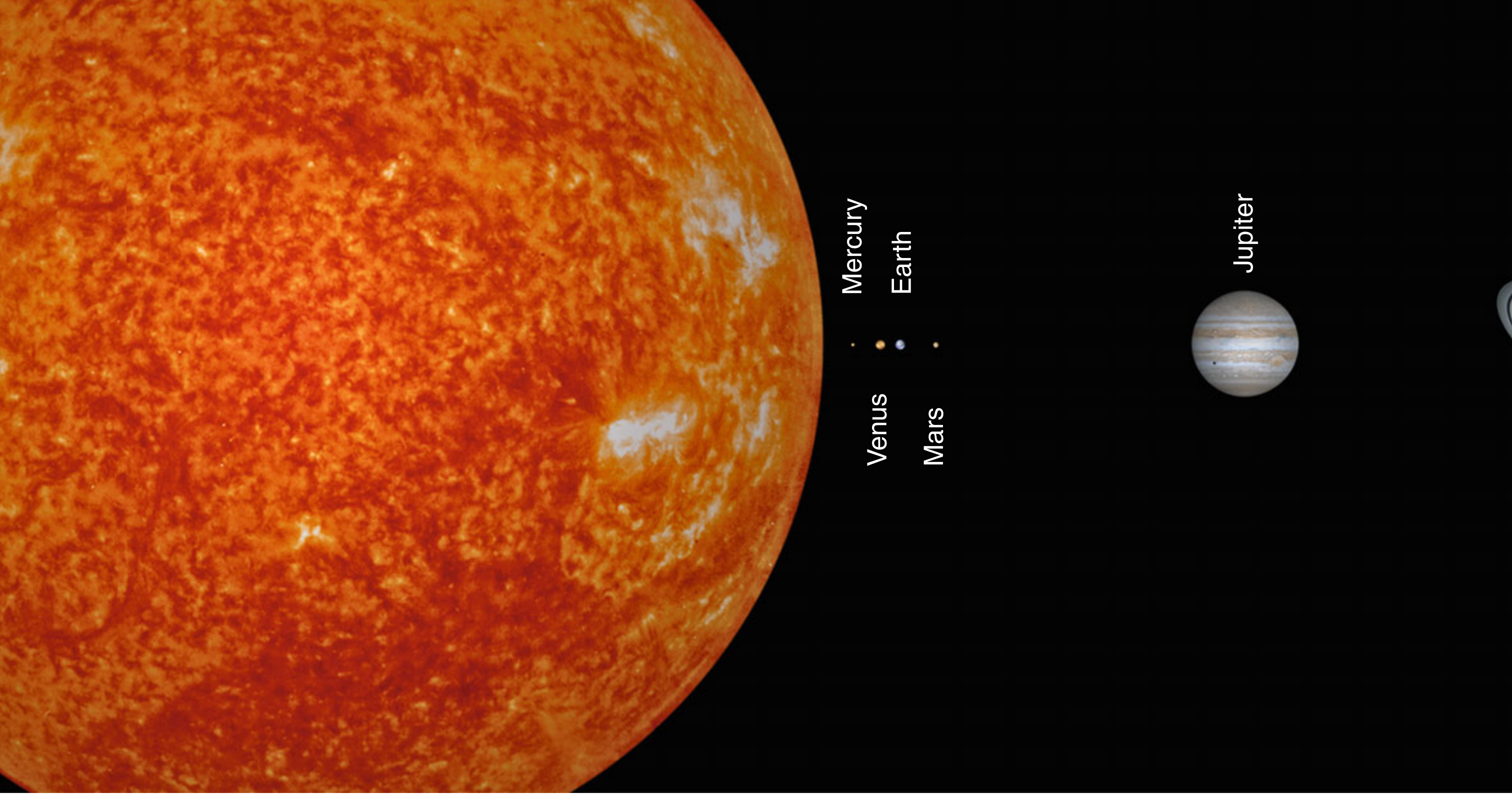
A unique image of the planets close to the Sun observed with the LASCO-telescope on SOHO. An occulting disk inside the telescope blocks the bright light from the solar disk creating an artificial solar eclipse. Mercury, Venus, Jupiter, Saturn, and the Pleiades are visible. Just outside the occulting disk one can see enormous ejections of gas from the hidden Sun. The horizontal strikes from the planets are artifacts from the digital camera (ESA/NASA).







The Sun and the planets, size to scale. The distance between them is not to scale (NASA).



The Sun and the eight planets (D. Jarvis).

The Size of the Solar System

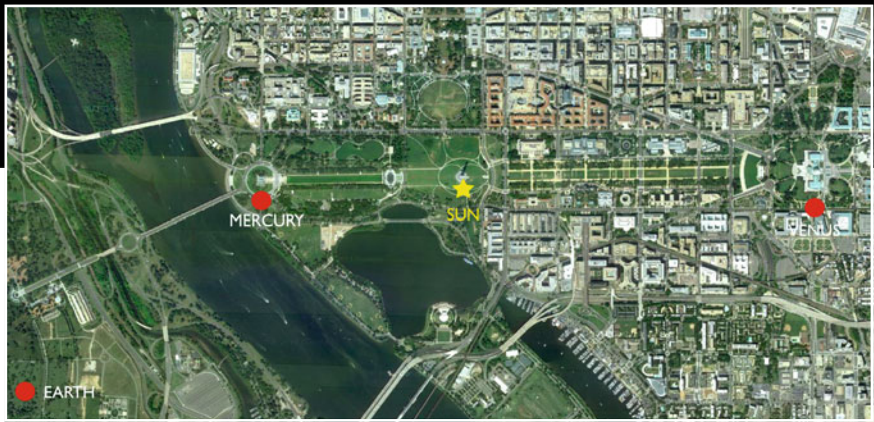
To better understand the enormous sizes in the Solar System, one can construct a model reduced by a factor of 1:10,000,000,000 (10 billion times smaller). In this scale, Earth would be 1.3 mm in diameter, the size of a needle head. The Moon would orbit 4 cm from Earth. The Sun would be the size of a grapefruit. If you hold up "Earth" and a friend holds up the "Sun," he or she has to stand 15 m away from you to get the scale right.

In such a model, Jupiter would be 1.5 cm in diameter and about 75 m from the "Sun." Saturn would be 150 m away and Uranus and Neptune 300 and 450 m, respectively. The closest star would still be 4,400 km from your Sun, about the distance between New York City and Los Angeles.

Saturn

Uranus

Neptune

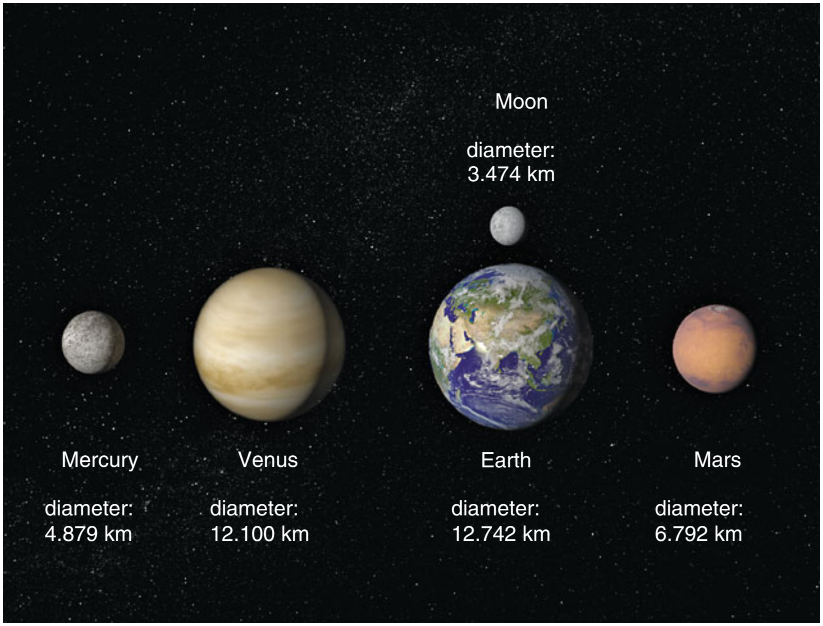


If Earth was the size of a basketball and the Sun was located near the Washington Monument in Washington, D. C., Earth would be near Arlington National Cemetery. Mercury would be almost by the Lincoln Memorial, Venus by the US Capitol, while Mars would be located by the National Arboretum. Uranus would be at Dulles International Airport and Neptune at Gettysburg (Google map).

The Rocky Planets

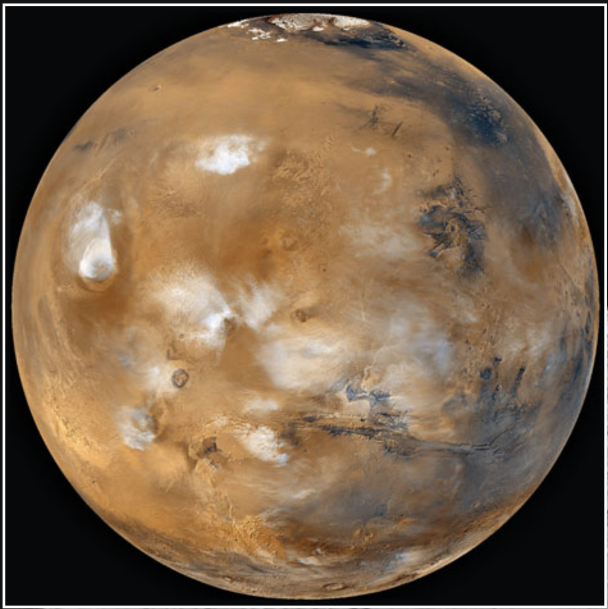
The innermost planets are all quite similar to Earth, consisting mainly of rock and metals and with a hard crust. They have a relatively high density, rotate very slowly, and have no rings and few moons orbiting them.

Earth is the largest and the only one with liquid water. Mars is the one most similar to Earth. Here we find old canyons where water may have flowed. Its polar caps are covered with ice. Several orbiters, landers, and robotic rovers have explored the Martian surface in great detail. The ultimate question is whether some sort of life has existed on Mars.



The four innermost planets to scale (T. Abrahamsen/ARS/NASA).

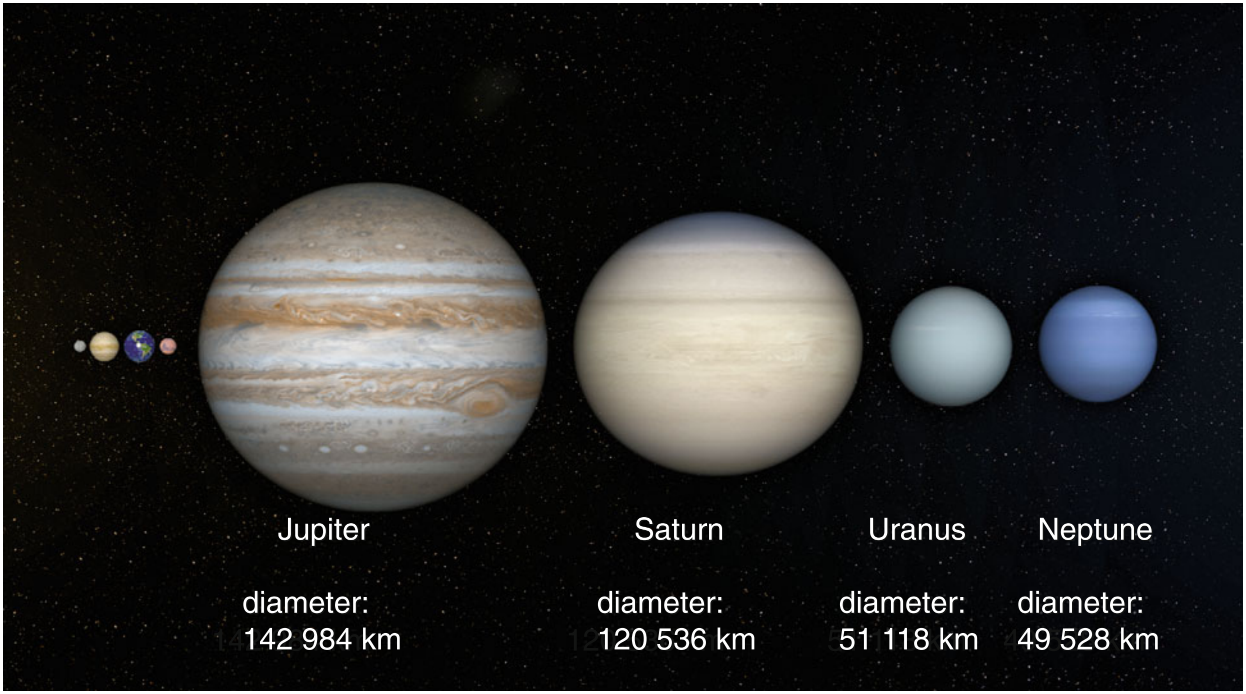
Panorama view from the Mars rover Spirit (NASA).



Mars with the reddish color and the ice-covered polar caps (NASA).

Venus is covered with thick clouds. With special instruments one can still take pictures through the clouds and see the surface (NASA).

Mercury with its numerous craters (NASA).



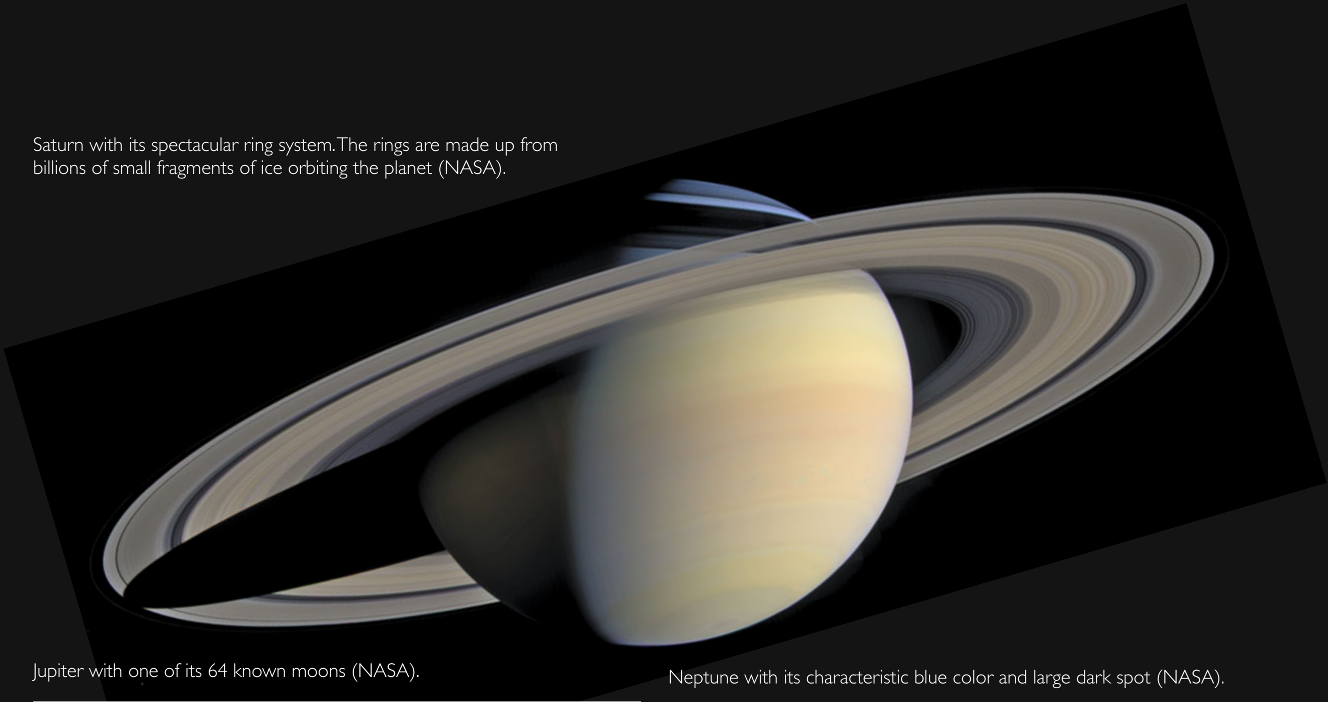
The large gaseous planets shown to scale. They are all much bigger than the inner rocky planets (T. Abrahamsen/ARS/NASA).

The Gaseous Planets

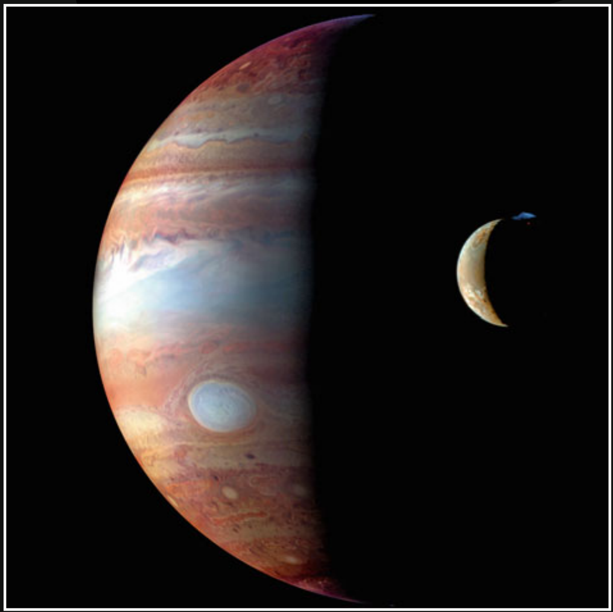
The outer planets are often called the gas giants (Jupiter, Saturn, Uranus, and Neptune), even though they both consist of gas, liquid, and ice. They mainly consist of hydrogen and helium, and their density is fairly low. Uranus and Neptune also contain large amounts of compressed water deep inside. They rotate much faster than the inner planets and have extensive atmospheres. Saturn is known for its amazing ring systems, but the other gas planets also have rings.

These giant planets all have a large number of moons. Jupiter has 64 known moons, while Saturn has 34 moons. One of Saturn's big moons, Titan, is quite mysterious, covered by a thick layer of clouds. In January 2005, the *Huygens* probe landed on Titan and sent back the first pictures to show us what it looks like on the surface.

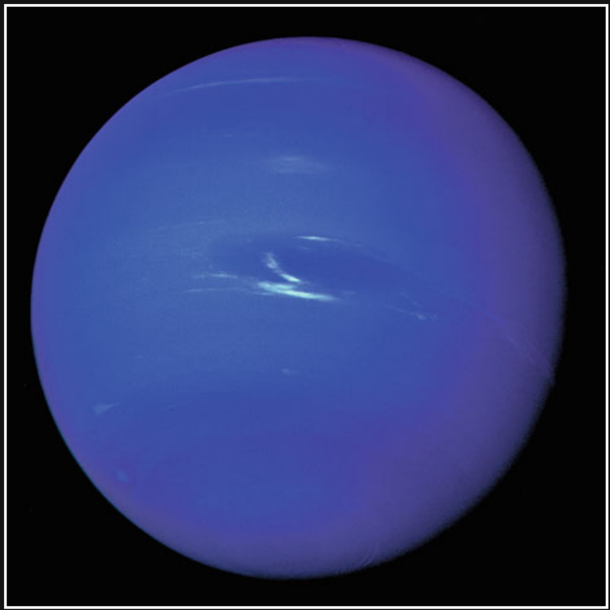
Saturn with its spectacular ring system. The rings are made up from billions of small fragments of ice orbiting the planet (NASA).



Jupiter with one of its 64 known moons (NASA).



Neptune with its characteristic blue color and large dark spot (NASA).



A spectacular sunset seen from the space shuttle. In the upper part, one can see a section of the robotic arm on the space shuttle (NASA).

The Sun and Earth

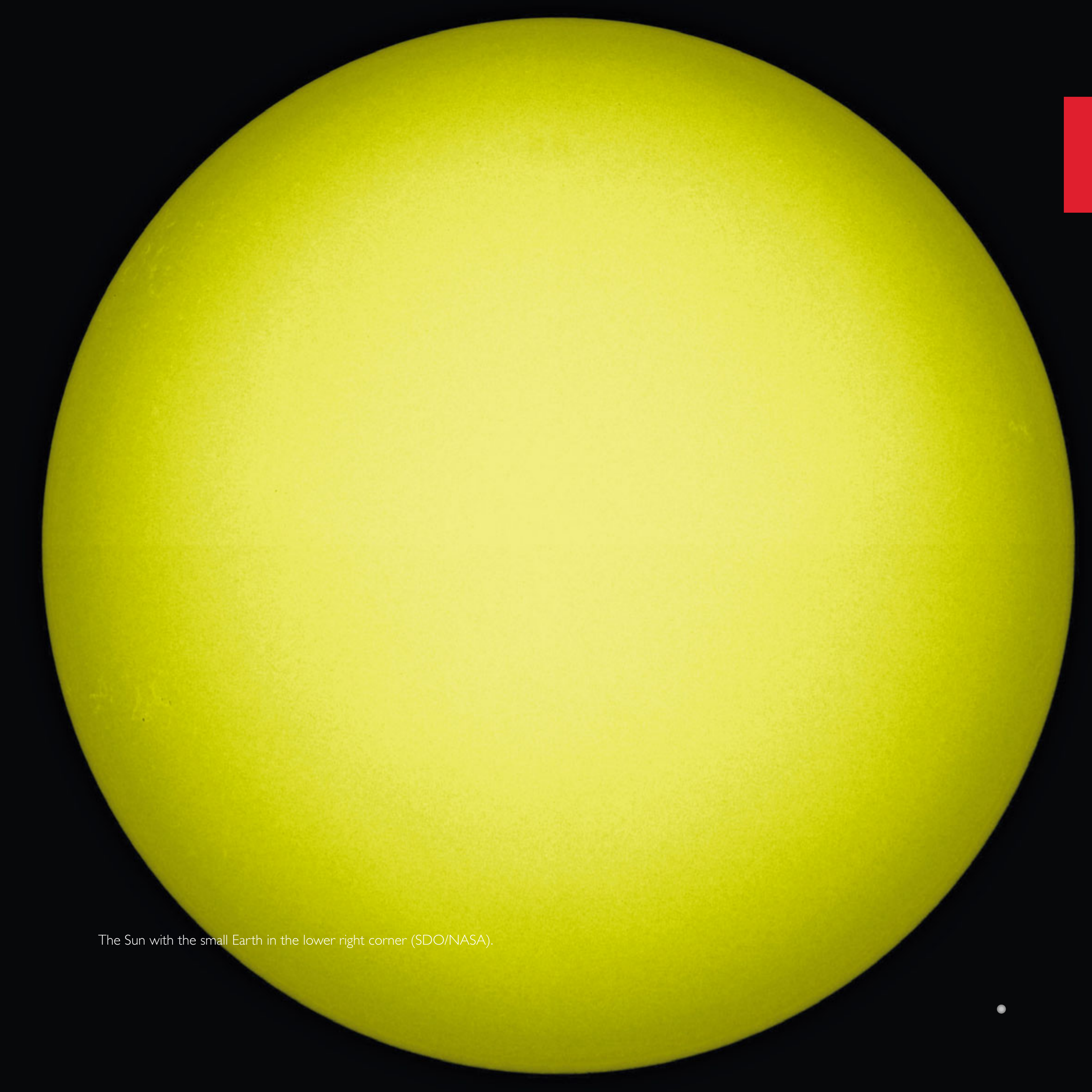
We often say that the Sun "rises" and the Sun "sets." However, we know that the Sun is not moving in that way, but rather it is the Earth rotating around itself. It takes Earth 24 h to rotate once. That is why we have day and night. Earth's rotation is also the reason for the apparent movement of the stars and planets over the night sky.

To the right is a picture of the Sun with Earth beside it. Are you having trouble seeing it? The reason is that the Sun is soooooooooooooo much bigger! You can find Earth as a small blue dot in the lower right corner.

Earth is about 13,000 km in diameter, while the Sun's diameter is about 1.4 million km. One can put 109 Earths side by side across the Sun. If one could fill the Sun with planets the size of Earth, it would fit 1.3 million planets.

Fascinating Facts: Since the Sun is over 300,000 times "heavier" than Earth, the gravity on the Sun will be much greater than here on Earth. If you weigh 35 kg on Earth you would weigh over 1,000 kg if you could stand on the Sun.

Fascinating Facts: Earth is "speeding" around the Sun at a velocity of 108,000 km/h without us being "blown" off its surface.



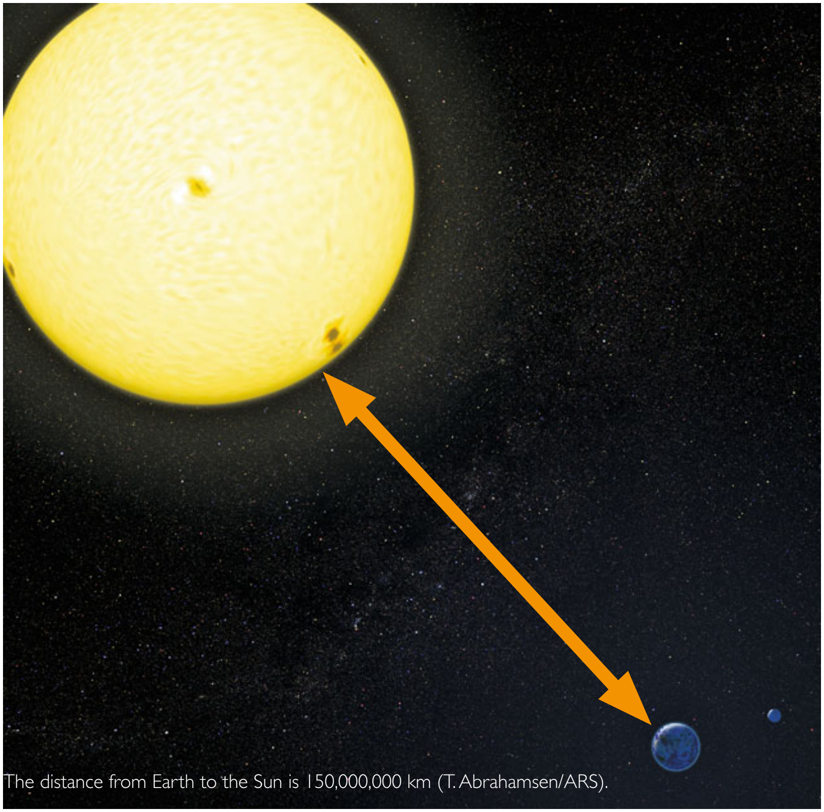
The Sun with the small Earth in the lower right corner (SDO/NASA).

The Distance to the Sun

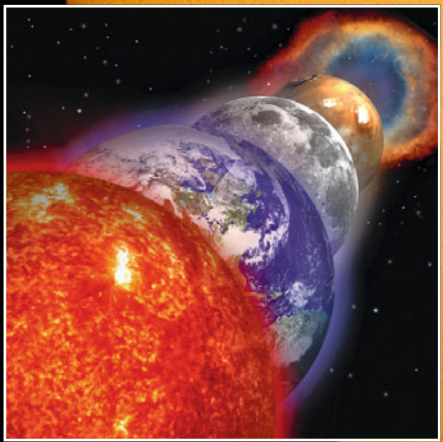
The Sun looks relatively small in the sky because it is so far away. The distance to the Sun is 150 million km, and the light spends 8 min and 20 s to reach Earth. If you could travel to the Sun with an aircraft, it would take you about 17 years to get there. How old would you be when you arrive? And how old would you be when you return to Earth?

Fascinating Facts: A distance of 150 million km is hard to grasp. If you had a piece of yarn that long and rolled it up, it would be a ball 75-m tall, weighing 60 million kg (or 60,000 m. t.). That is approximately 30 space shuttles. It would be enough yarn to knit sweaters for 200 million people.

Driving a car at 100 km/ph it would take you 170 years. A horse running 13 km/h would spend 1,317 years. If you walked (5 km/h) it would take you 3,424 years.

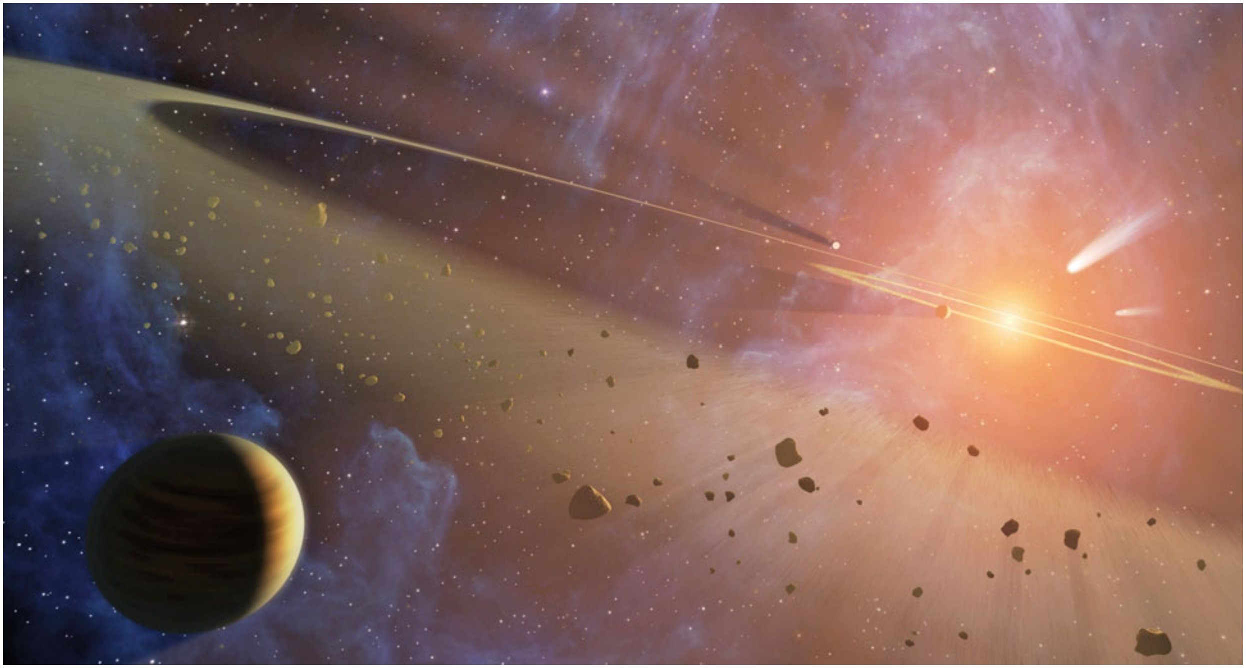


The distance from Earth to the Sun is 150,000,000 km (T. Abrahamsen/ARS).



The distance between the Sun and the planets is tiny compared to the distances between objects out in the universe (NASA).

An airplane with its vapor trail is passing in front of the Sun, and a few dark spots called sunspots are visible (J. Koeman).



There are more than a million asteroids orbiting the Sun, and together with comets, they are an important part of our Solar System (NASA/JPL-Caltech).

Asteroids and Comets

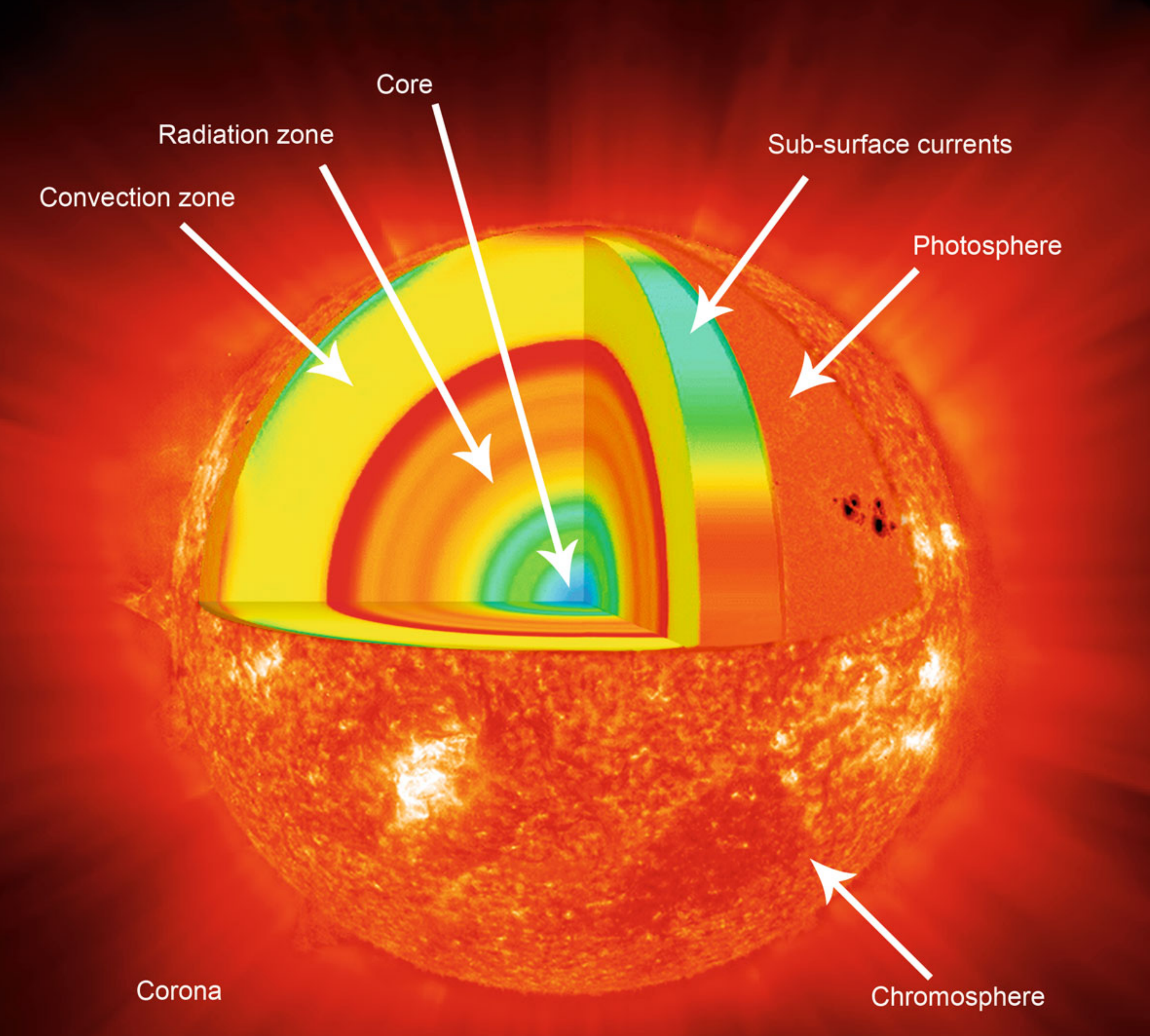
Between Mars and Jupiter we find the Asteroid Belt, where a large number of asteroids orbit the Sun. Asteroids are irregular rocks, the largest a few hundred kilometers in diameter. On rare occasions, asteroids can stray off course and can hit Earth. Such a collision would be catastrophic for our society, and a surveillance system to detect Earth-directed asteroids has been put in place.

Comets consist of ice, rocks, dust, and frozen gas and orbit the Sun in very elliptical orbits. Some of them orbit the Sun in a few years, while others spend a million years traveling this distance. When comets get closer to the Sun, they heat up and ice and frozen gas evaporates. Together with the dust they form a gigantic halo around the comet nucleus. The radiation from the Sun will "blow" gas and dust particles away from the nucleus and form the characteristic comet tail.

Comets leave behind a stream of dust and particles. When Earth is passing through the debris from a comet, we experience a large number of meteors – what we call a meteor shower (NASA/JPL-Caltech/P. Pyle).

Comet Hale Bopp on April 8, 1997. The comet displays both a broad dust and gas tail and has an orbital period of about 2,400 years (M. Druckmuller).

The asteroid Ida with its small moon Dactyl photographed by the Galileo spacecraft. Dactyl is the first asteroid moon to be discovered (NASA).



Pål Brekke, *Our Explosive Sun*,
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The structure of the Sun from the core to the outer atmosphere (S. Hill/ESA/NASA).

THE SUN, FROM THE INSIDE OUT

The Aztec calendar stone, or Stone of the Sun (*Piedra del Sol* in Spanish), is a large monolithic sculpture that was excavated in the Zócalo, Mexico City's, main square, on December 17, 1790. The stone was carved in the late 1,400 s. In the stone's center is the Sun god, Tonatiuh. The rest of the carvings illustrate Aztec cosmology – the Aztecs believed that prior to their existence, the world had gone through four periods ("suns") of creation and destruction.

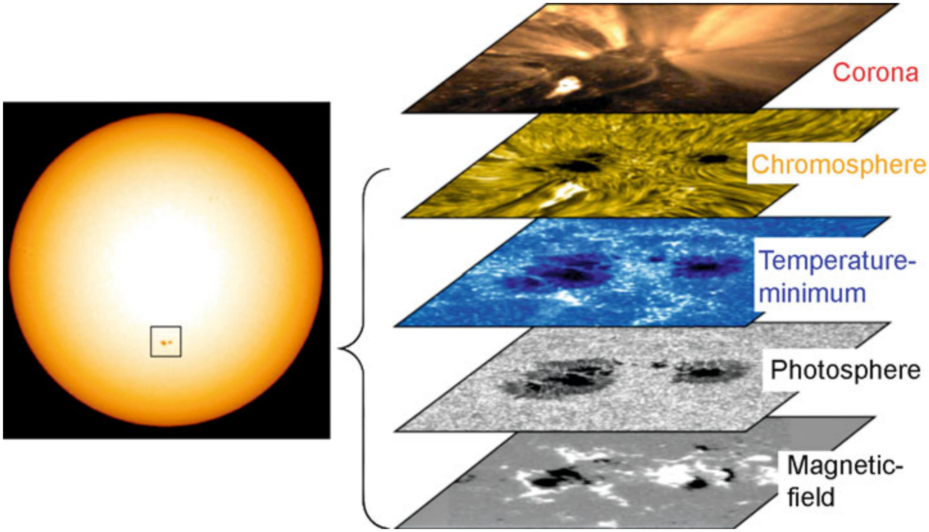
The Structure of the Sun

The hot compact core of the Sun – where the energy is created – has a radius of about 175,000 km. Outside the core is a layer where the energy is transported by electromagnetic radiation or photons. This layer is called the radiation zone.

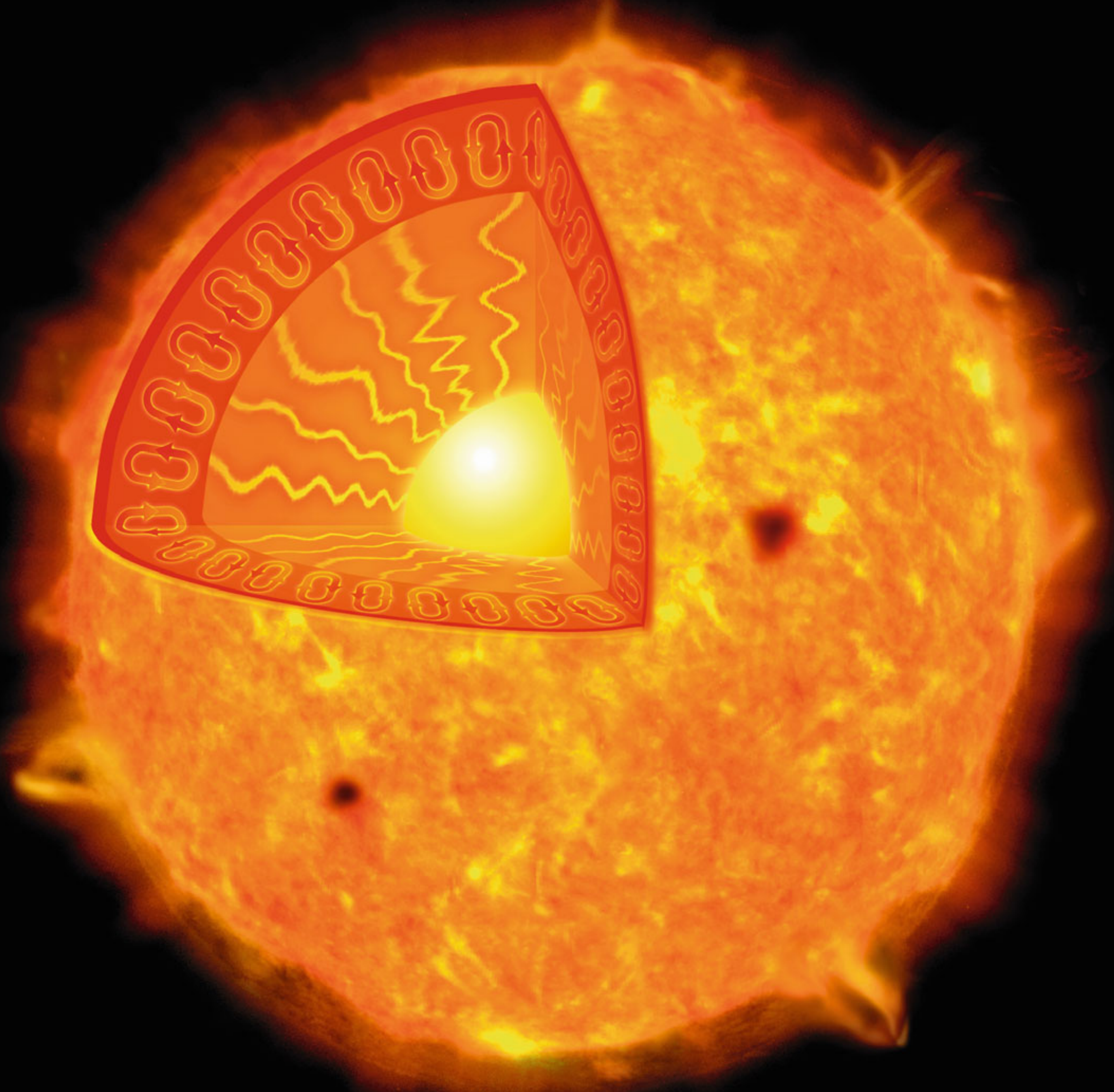
The radiation is transferred by its interaction with the surrounding atoms. Some of these atoms are able to absorb the energy, store it for a while, and then later emit that energy as new radiation. In this way, the energy that is generated in the core is passed from atom to atom throughout the radiation zone.

Further out, we find the convection zone, where the energy is transported as a turbulent churning motion similar to a pot of boiling soup.

The visible surface, the photosphere, is only about 400-km thick. Above the photosphere we find the chromosphere, a layer of thin hot gas extending to a few thousand kilometers. Above the chromosphere is the corona, the outermost part of the solar atmosphere.



By using different filters in a telescope, one can study the different layers of the solar atmosphere (NAOJ/ITA).



The structure of the Sun: the inner core, the radiation zone (where energy and particles radiate toward the surface), and the convection zone, where energy circulates like water bubbling in a pot (NASA/CXC/M. Weiss).

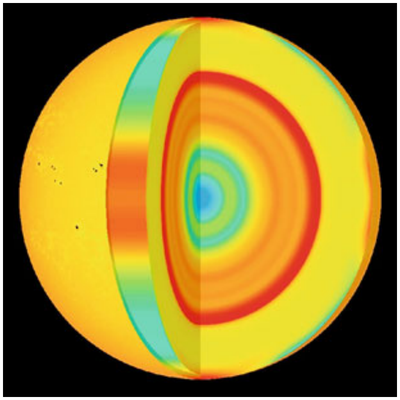
A Spinning Sphere of Gas

The sun is made of gas, mostly hydrogen and helium. This hot sphere of gas is rotating just as Earth is. What is interesting about the Sun is that different latitudes rotate with different speeds. The gas around the equator rotates faster than the gases closer to the poles. We call this differential rotation. It takes the gas by the equator about 25 days to move around the Sun one time, while close to the poles it takes 35 days.

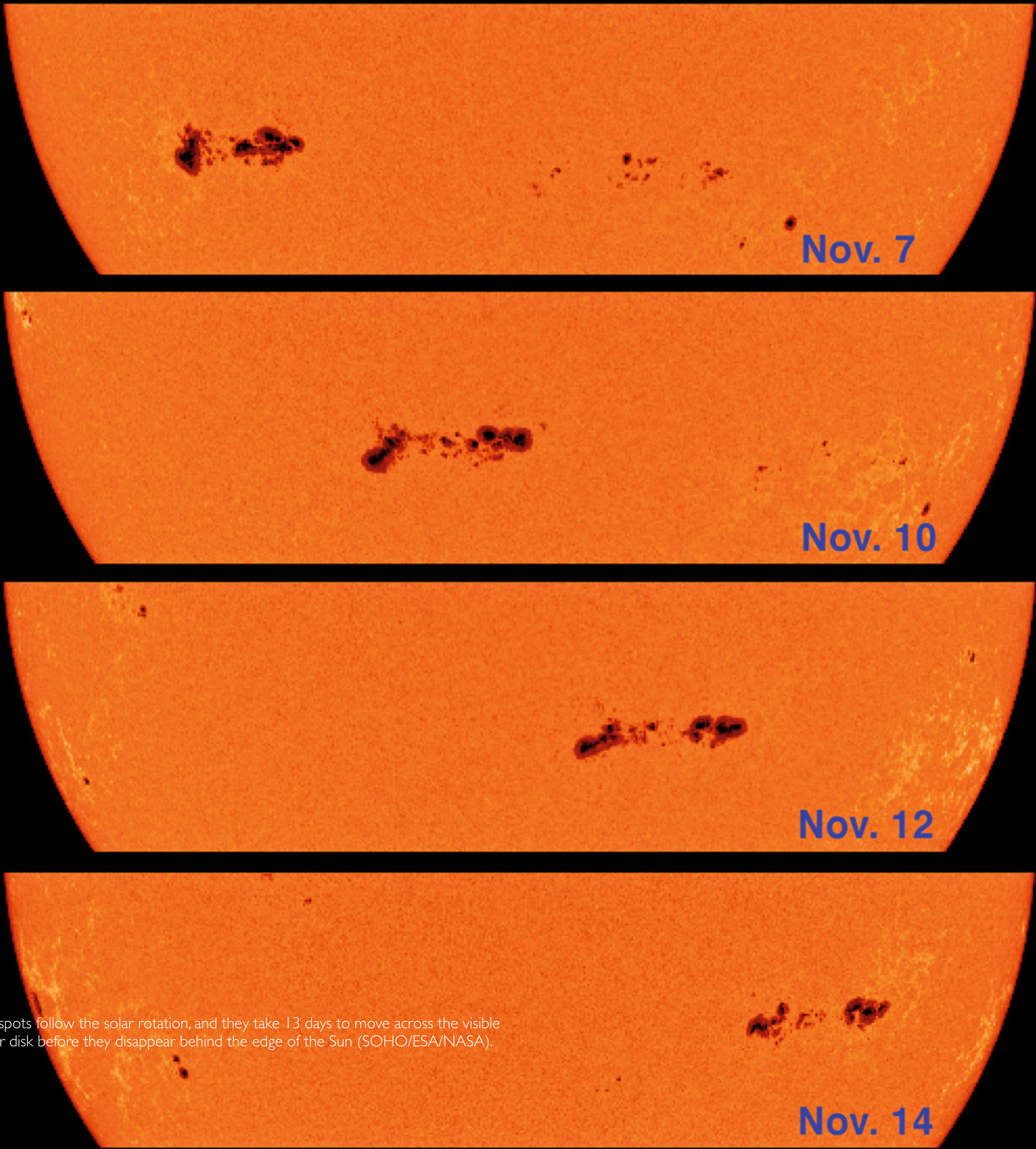
On average it takes the Sun 27 days for it to rotate one time around its axis. What is even stranger is that the inner part of the Sun seems to rotate as a solid sphere. It is only the outer 30% of the Sun, the convection zone, that experiences differential rotation. At the bottom of the convection layer, two layers with different rotation speeds meet, creating "friction." This is the area, we believe, where the Sun's magnetic field is created.

The rotation of the Sun was first noticed and described by Galileo, who studied the Sun with his telescope in 1610. He noticed that sunspots moved each day from east to west on the solar disk as the Sun rotated. You can easily study the rotation of the Sun by observing the movements of sunspots across the solar disk. You can use a special solar telescope or look at updated solar images from satellites over several days (e.g., http://sdo.gsfc.nasa.gov/). But you can NEVER directly observe the Sun without special filters, glasses, or other specially designed instruments.

The Sun rotates faster along the equator than closer to the poles (T. Abrahamsen/ARS).



A cutaway of the Sun showing that the outer layer rotates with different speeds, while the inner part of the Sun rotates as a solid sphere (SOHO/ESA/NASA).



Sunspots follow the solar rotation, and they take 13 days to move across the visible solar disk before they disappear behind the edge of the Sun (SOHO/ESA/NASA).

The Core of the Sun

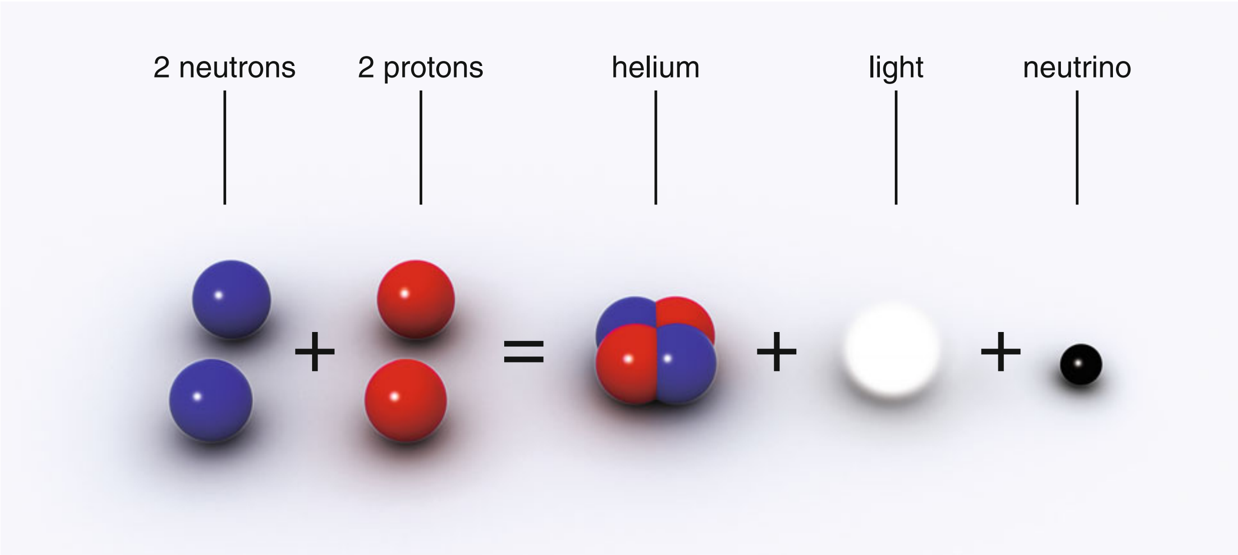
The conditions in the solar core are extreme; this area is kind of like a nuclear power plant. The temperature is over 15 million degrees Celsius, and the enormous pressure is pushing the atoms very close together, causing them to collide with each other all the time. Sometimes hydrogen nuclei combine to form helium nuclei. In this process, some of the mass is converted to the light particles we call gamma rays. This is the energy that keeps the Sun shining. This process also creates particles called neutrinos.

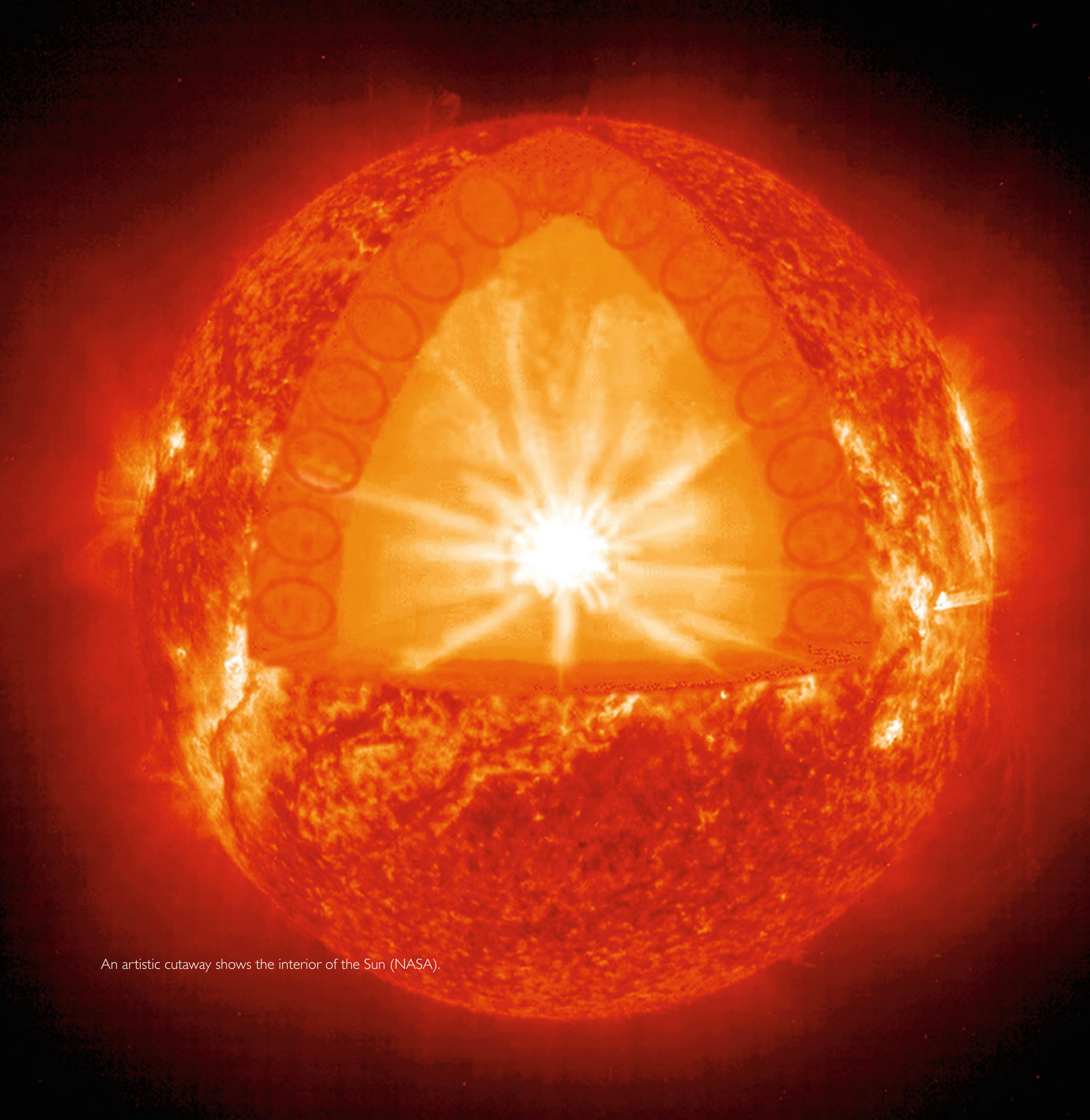
Each second about 700 million tons of hydrogen is converted into helium, and about 4 million tons of mass is converted into radiation (gamma rays) and neutrinos. The question is, of course: Will the Sun run out of hydrogen? Yes, but luckily it has enough hydrogen to shine for another 5 billion years.

FASCINATING FACTS: The energy production of the Sun is an incredible 3.86 × 10^{26} W, or 386 billion billion megawatts. The energy the Sun sends out into space in 1 s is more than Norway's electricity consumption in 600 million years.

The gas in the solar core has a density 150 times greater than water. One milk carton with this solar gas would weigh 150 kg. In the outer layers of the Sun, the density is much less than water, so the average density of the entire Sun is more or less like yogurt.

A simplified illustration of the process that converts hydrogen into helium and that generates light and particles (T. Abrahamsen/ARS).



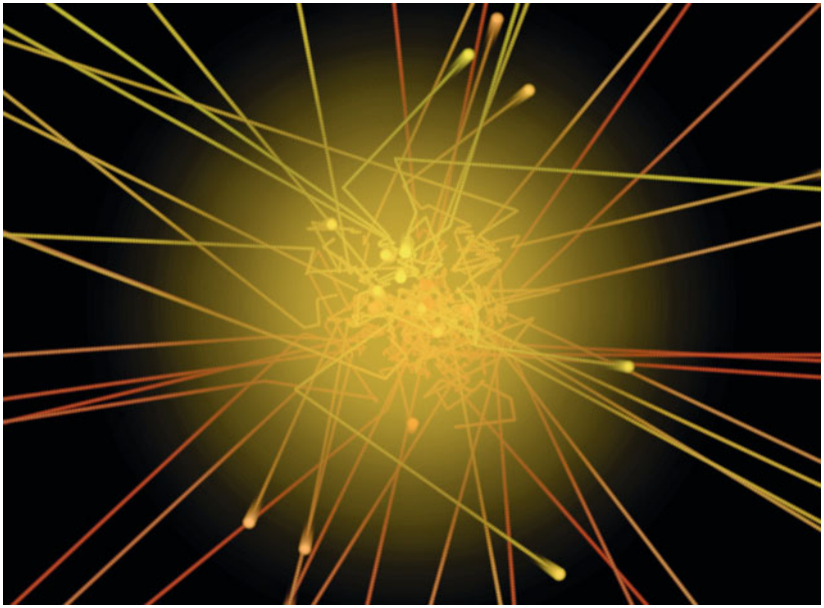


An artistic cutaway shows the interior of the Sun (NASA).

The Journey of Light from the Sun

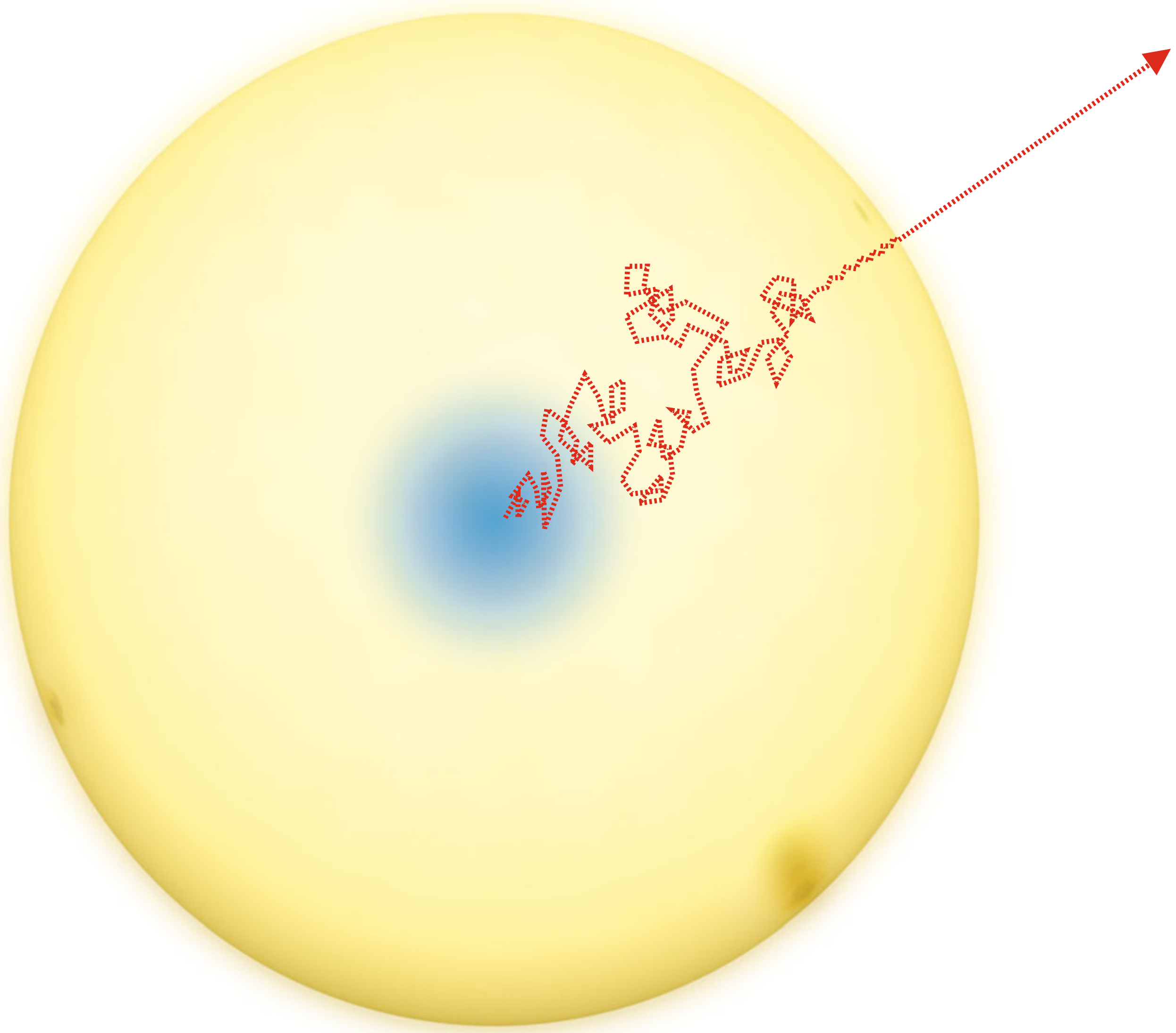
On its way out of the solar core the light particles collide with other atoms, which changes their directions all the time, like a ball in a pinball game. In this way, they zigzag in a random pattern inside the radiation zone. It can take as much as 200,000 years before the light particles manage to push their way out of the radiation zone that reaches two-thirds of the way out of the Sun. Outside this region the energy is transported up toward the surface by currents of hot gases. Here the gas bubbles up just like warm soup in a pan. Then, the light can escape freely out in space. Eight minutes and 20 s later the light reaches Earth, and we feel the heat on our bodies. It is odd to think that this is "old" energy that originated inside the Sun 200,000 years ago – when the Neanderthals walked Earth.

The neutrons, however, race straight out of the core with the speed of light, since nothing is stopping them. They race out into space straight through Earth and are very hard to detect.



The light particles (gamma rays) that are formed in the core will immediately collide and be re-emitted many times in a random direction before they can escape the Sun (Jean-Francois Colonna).

FASCINATING FACT: Each second about 30 billion neutrinos will pass through one of your fingernails!



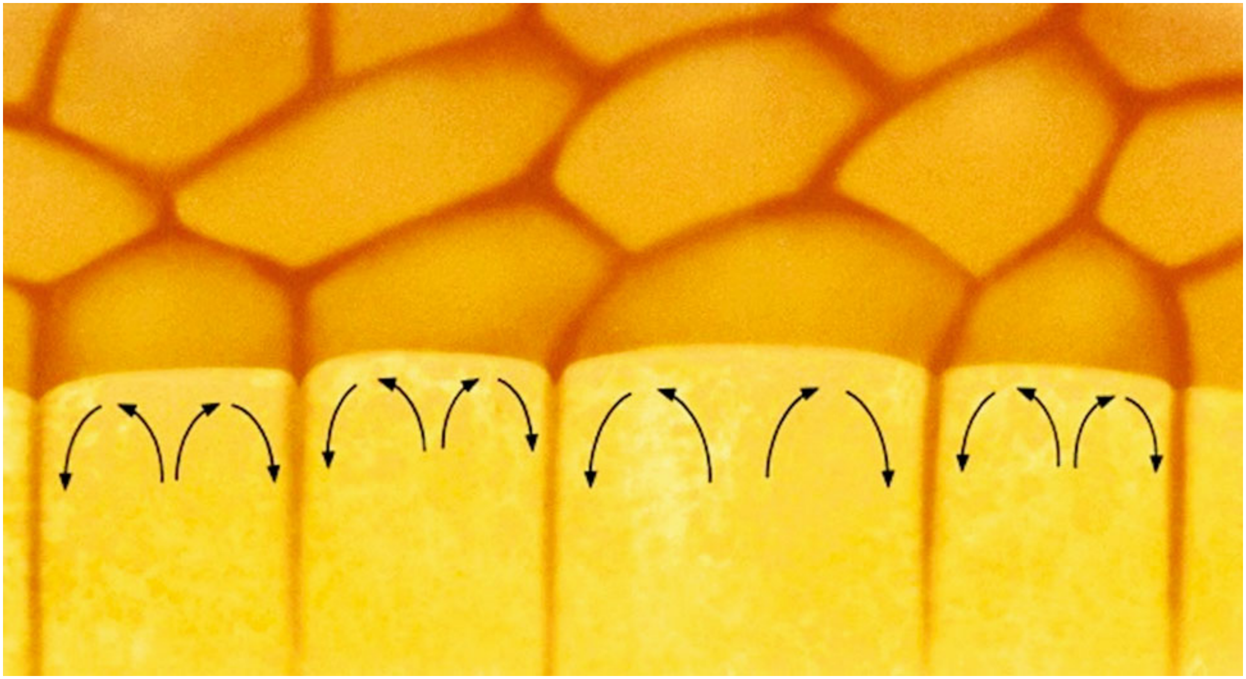
The light particles move in a random pattern for about 200,000 years before they reach the convection layer (T. Abrahamsen/ARS).

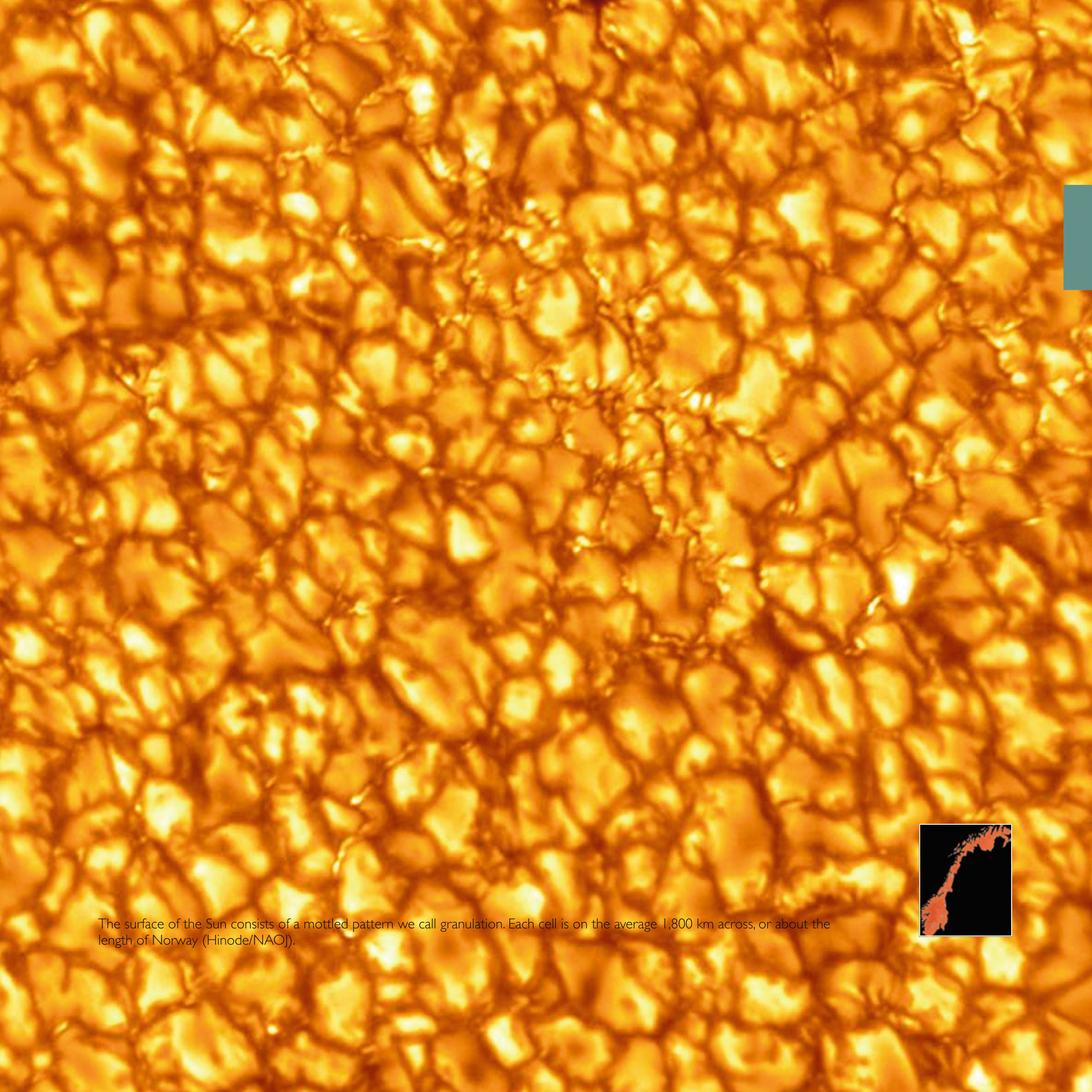
The Solar Surface: The Photosphere

Most of the energy from the Sun is radiated out from the surface, which we call the photosphere. This is the part of the Sun we actually can see from Earth with the naked eye (see picture on the right). The photosphere is not a solid surface but a layer of gas and part of the Sun's atmosphere. We still call this layer the surface. It is about 400-km thick and holds a temperature of about 5,000°C. It is covered by a cell-like pattern we call granulation and shows how hot gas bubbles up from deeper layers, cools down at the surface, and sinks down again in thin darker lanes. This is similar to what you can see in a pot of simmering soup. The granules are about 1,000 km in diameter, with a lifetime of about 8 min. In recent years, we have also discovered that the photosphere moves up and down about 15 km with different periods. Today we know that this is caused by sound waves that are traveling inside the Sun and reflecting back from inside of the surface, pushing it up and down.

FASCINATING FACT: An area on the surface of the Sun that is the size of a stamp shines as bright as 150,000 candles.

Warm gas is rising in the central part of the granulation cells, cools down while it floats horizontally out toward the darker lanes, where it sinks down again (NASA).





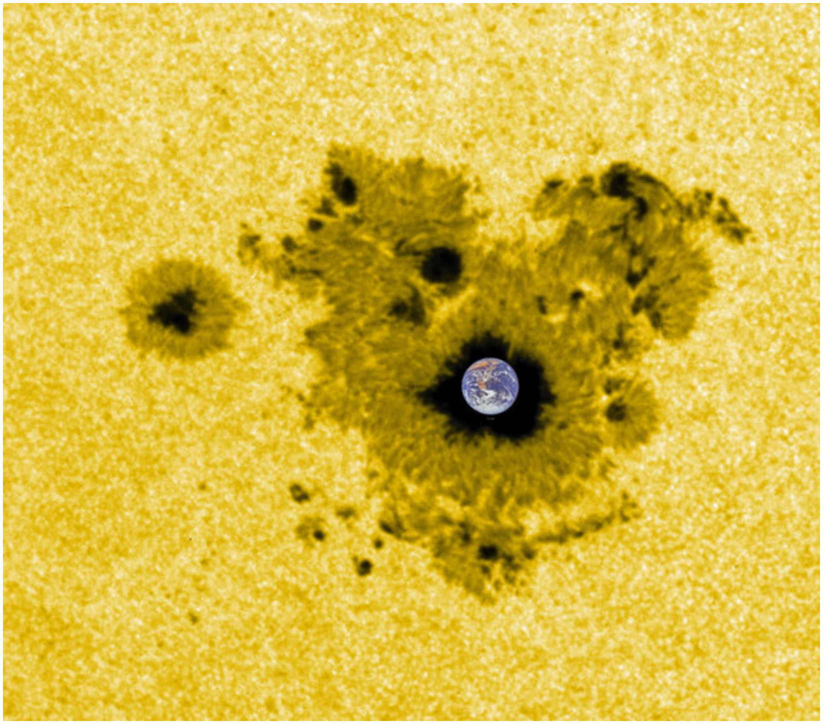
The surface of the Sun consists of a mottled pattern we call granulation. Each cell is on the average 1,800 km across, or about the length of Norway (Hinode/NAOJ).

Sunspots

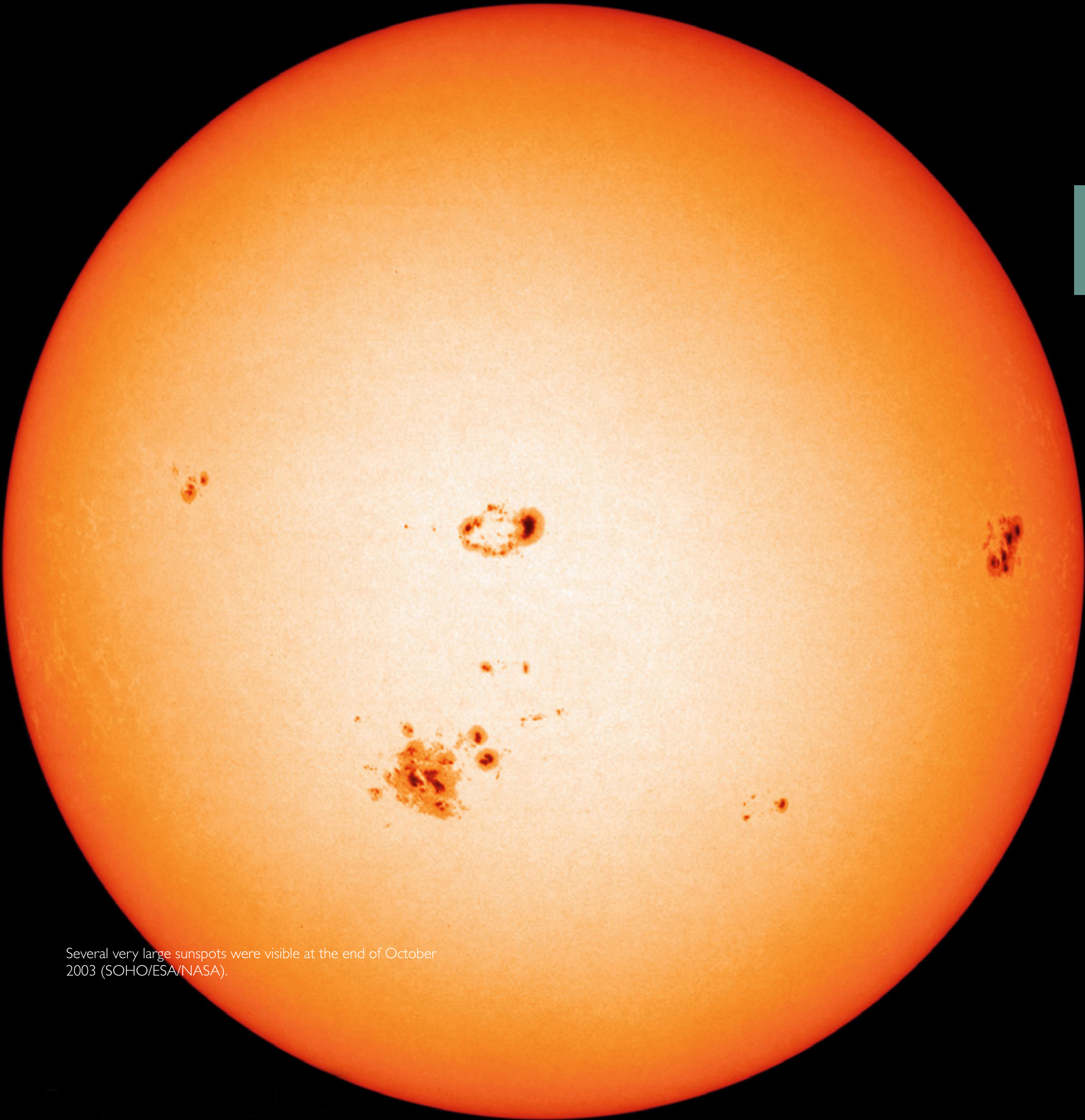
The most visible features on the solar surface are sunspots. Sunspots look like dark blemishes on the surface of the Sun. Sunspots are formed when a strong magnetic field in the solar interior pushes itself out through the surface. The strong magnetic field will block some of the upwelling energy from reaching the surface in these regions, making them somewhat cooler. Thus, they look darker. The magnetic field in sunspots can be 10,000 times stronger than Earth's magnetic field.

A sunspot is not as dark as it looks. The temperature in a spot is about 1,500°C lower than the surrounding temperature in the photosphere. It is a contrast effect that makes the sunspots look dark. If you could place a sunspot on the night sky, it would shine brighter than the Moon.

Sunspots can be very big, up to 50,000 km across, which means that they are tens of times bigger than Earth. When the Sun is low in the horizon and hazy, it is possible to see large sunspots with the naked eye. However, you should not try to do this, since the powerful sunlight can damage your eyes.



Close-up of a sunspot observed with NASA's TRACE satellite. Earth fits well inside the spot (TRACE/Lockheed).

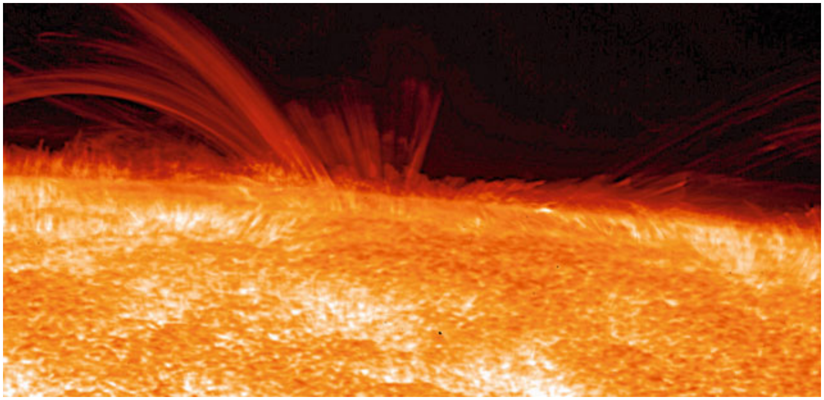


Several very large sunspots were visible at the end of October 2003 (SOHO/ESA/NASA).

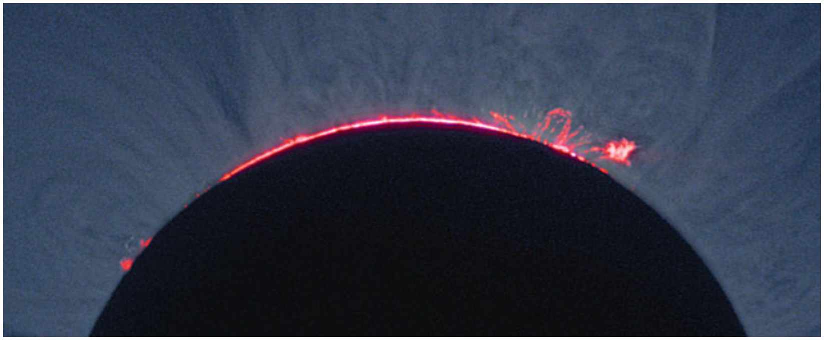
The Sun's Atmosphere: The Chromosphere

Above the photosphere we find the lower solar atmosphere, called the chromosphere. This is a pinkish layer of gas that can only be seen during a total eclipse or by using special telescopes, preferably in space. The chromosphere means "color sphere." It extends 3,000 km out from the photosphere. In the lowest part of the chromosphere, the temperature continues to decrease down to about 4,500°C. But then something strange happens – the temperature starts to increase again as we move further out. In the outer part of the chromosphere, the temperature reaches 30,000–70,000°C. This layer is mainly emitting ultraviolet radiation and thus cannot be studied in detail from the ground.

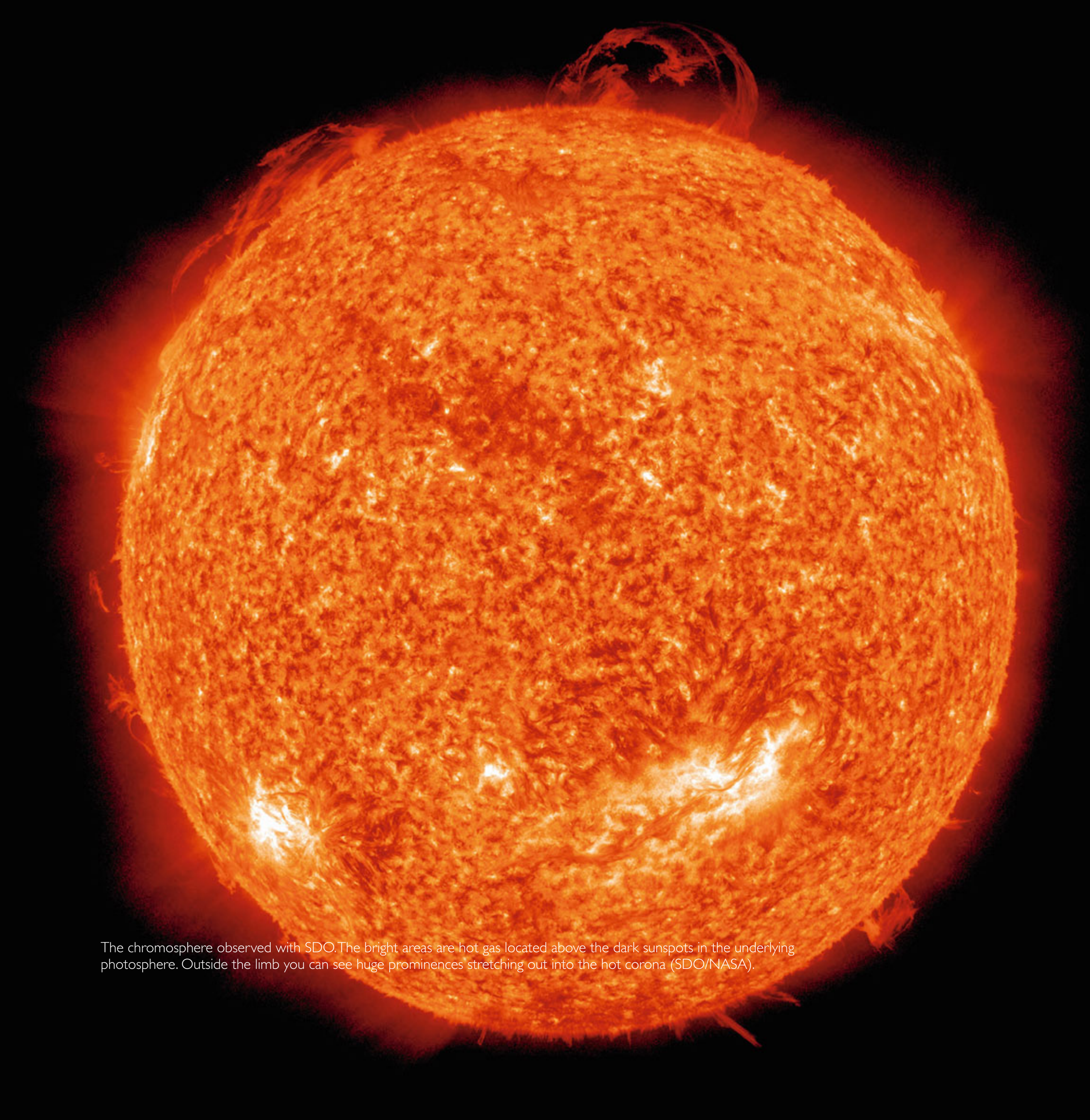
Just outside the chromosphere the temperature starts to increase very rapidly and we find the outer solar atmosphere – the corona.



The chromosphere is very structured; on this image one can see large magnetic loops rising up above the solar limb (Hinode/NAO).



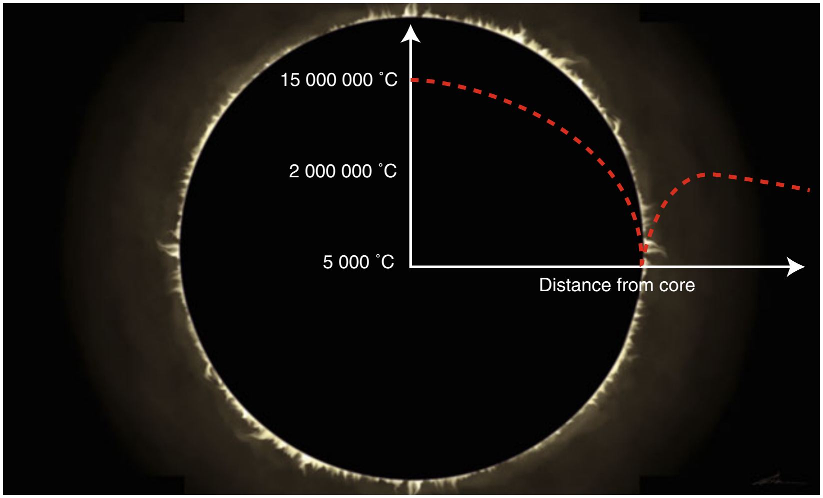
The chromosphere seen during a total eclipse. Large flame-like prominences rise up in the corona (M. Druckmuller).



The chromosphere observed with SDO. The bright areas are hot gas located above the dark sunspots in the underlying photosphere. Outside the limb you can see huge prominences stretching out into the hot corona (SDO/NASA).

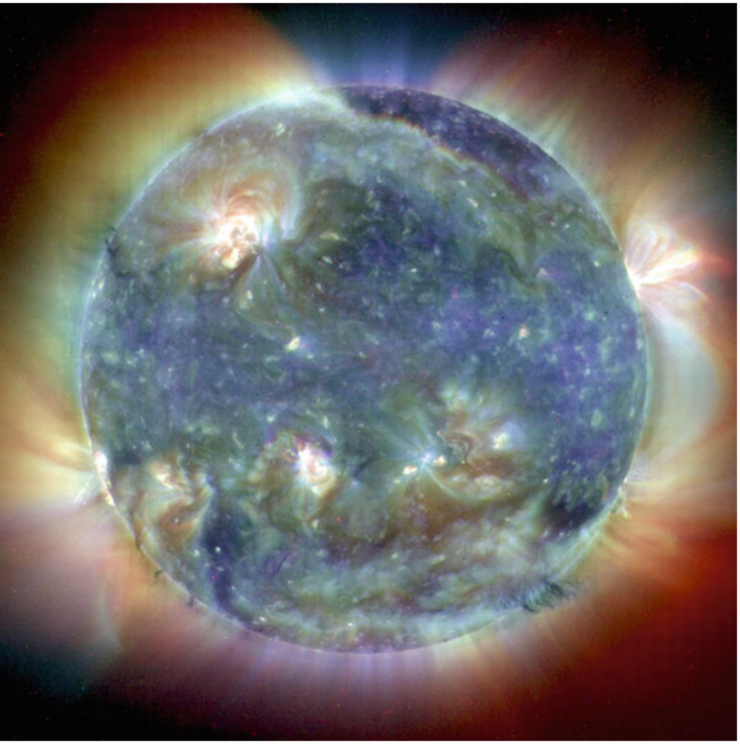
The Outer Solar Atmosphere: The Corona

The corona is the outer part of the solar atmosphere and consists mostly of hydrogen gas. The temperature is between 1 and 2 million degrees Celsius. The density is very low, less than a millionth of the air density at Earth. The corona emits very little light, so it is impossible to see it every day due to the strong light from the photosphere and the scattered light in Earth's atmosphere. Only during a total solar eclipse, when the Moon passes in front of the Sun and blocks the strong light from the photosphere, can we see the spectacular corona with the naked eye. With special telescopes that make artificial eclipses, it is possible to study the corona.

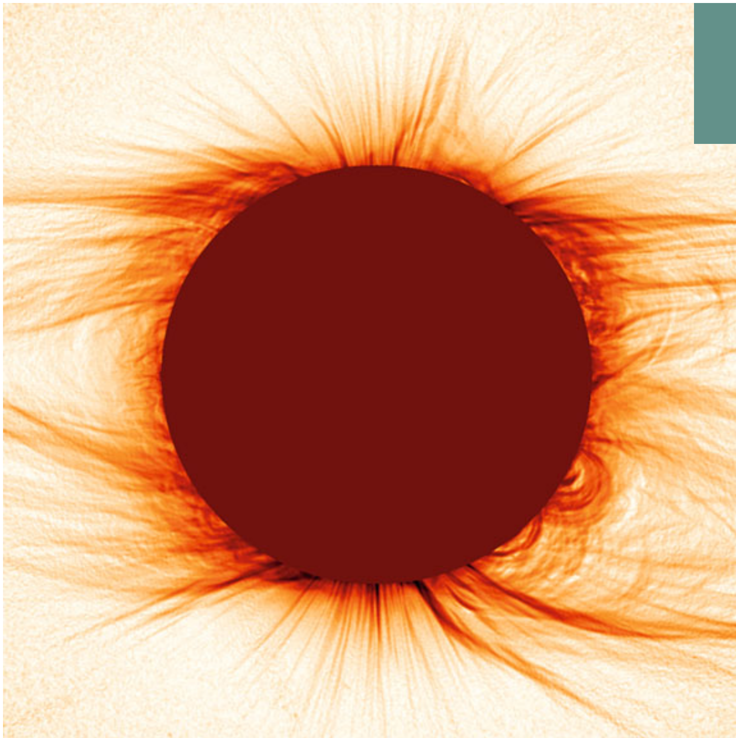


From the Sun's core the temperature decreases from 15 million degrees to 5,500 degrees Celsius at the surface (photosphere). Up through the chromosphere and corona the temperature starts increasing again (T. Abrahamsen/ARS).

The hot corona is one of the Sun's biggest mysteries. The energy from the superhot inner part of the Sun must in some unknown way be able to pass through the relatively cold photosphere and chromosphere without heating these layers. The energy then heats the corona to several million degrees. Imagine you are sitting in front of the fireplace and feel the heat from the fire. If you move away from it, you feel less heat. If you suddenly feel more heat again at the other end of the room you would wonder how the fireplace could heat the air in the opposite part of the room without heating the air between. The Sun manages this in some strange way. Nobody has the complete answer to this mystery yet, but it probably involves the Sun's magnetic fields. It may also involve sound waves that travel out through the atmosphere and dump the energy up in the corona.



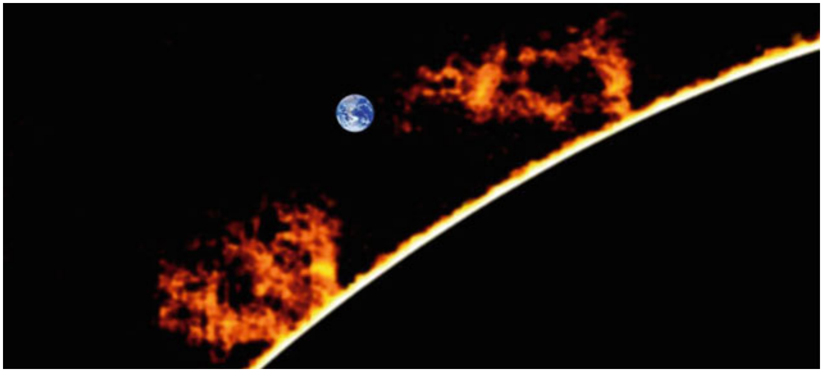
By observing the Sun with instruments that only detect ultraviolet light, one can observe the structure's hot corona (SOHO/ESA/NASA).



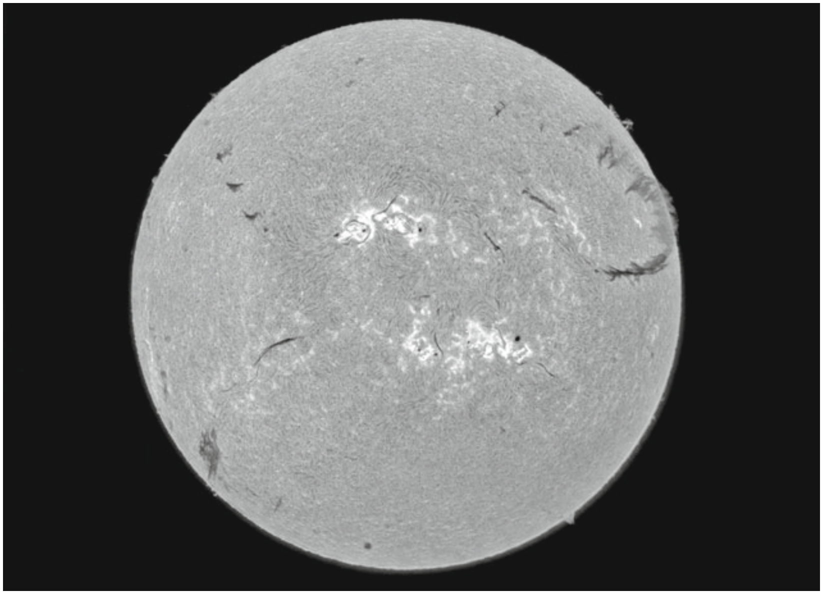
The mysterious solar corona observed during a total solar eclipse on February 26, 1998. All the structures and arcs in the corona are outlining the Sun's magnetic field, which "shapes" the coronal gas (High Altitude Observatory).

Prominences

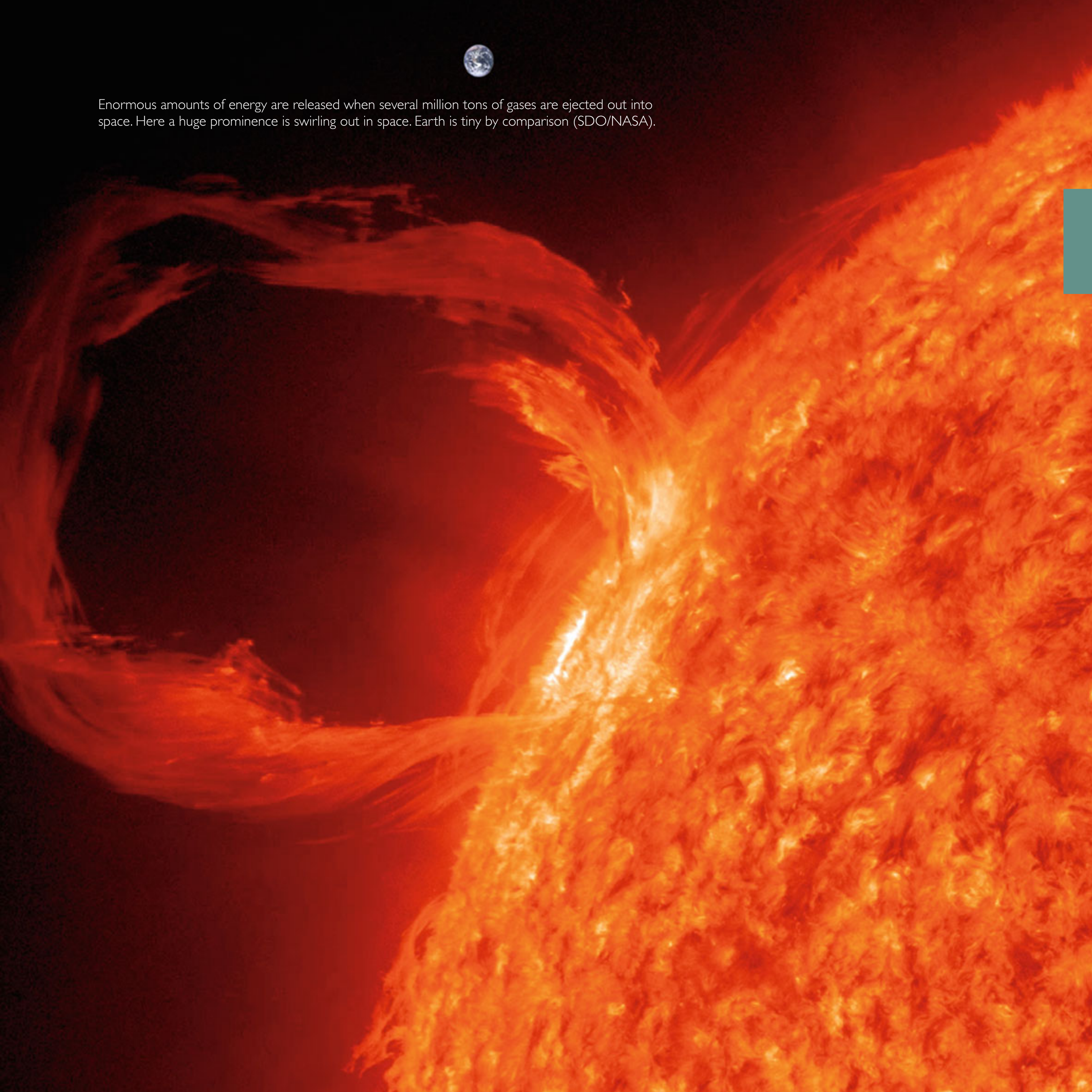
Prominences are chromospheric gas that is suspended up in the hot corona by strong magnetic fields. They can be seen as bright structures above the solar limb. When these same structures are seen against the solar disk, they look dark, since they absorb the bright light from the surface. They are then called filaments. Quiescent prominences are stable, change only slowly, and can last for several months. They can be 8,000-km thick and reach heights of 50,000 km. Active prominences often occur near sunspots and they change fast. Sometimes they can erupt and be ejected out into space. If this cloud of gas hits Earth's magnetic field, we experience strong auroras.



Prominences that are lifted up and suspended in the hot corona. This image was taken with a telescope that can block out the bright light from the solar disk (M. Zinkova).



When prominences are observed against the bright solar disk, they look dark and are called filaments (Big Bear Solar Observatory).

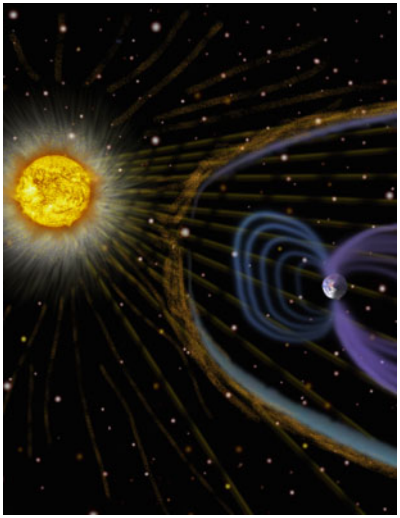


Enormous amounts of energy are released when several million tons of gases are ejected out into space. Here a huge prominence is swirling out in space. Earth is tiny by comparison (SDO/NASA).

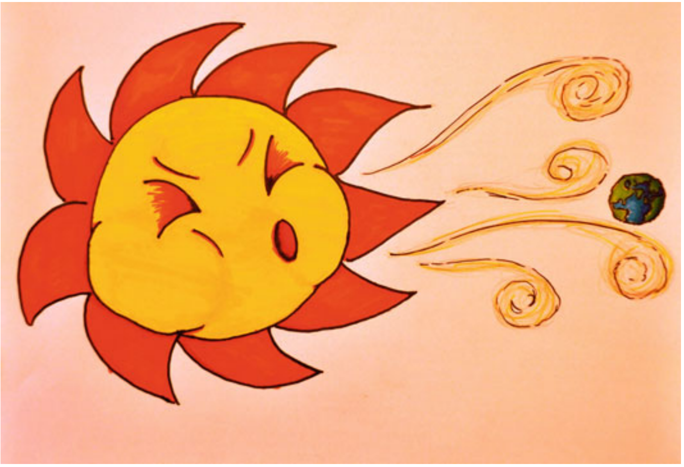
The Solar Wind

Did you know that the Sun can produce wind? This is not a breeze you can sail with here on Earth. In addition to heat and light, the Sun sends out a continuous stream of charged particles we call the solar wind. This stream mainly consists of electrons and protons. The solar wind blows out into the Solar System at a typical speed of 1.6 million km/h and would be lethal for humans without protection.

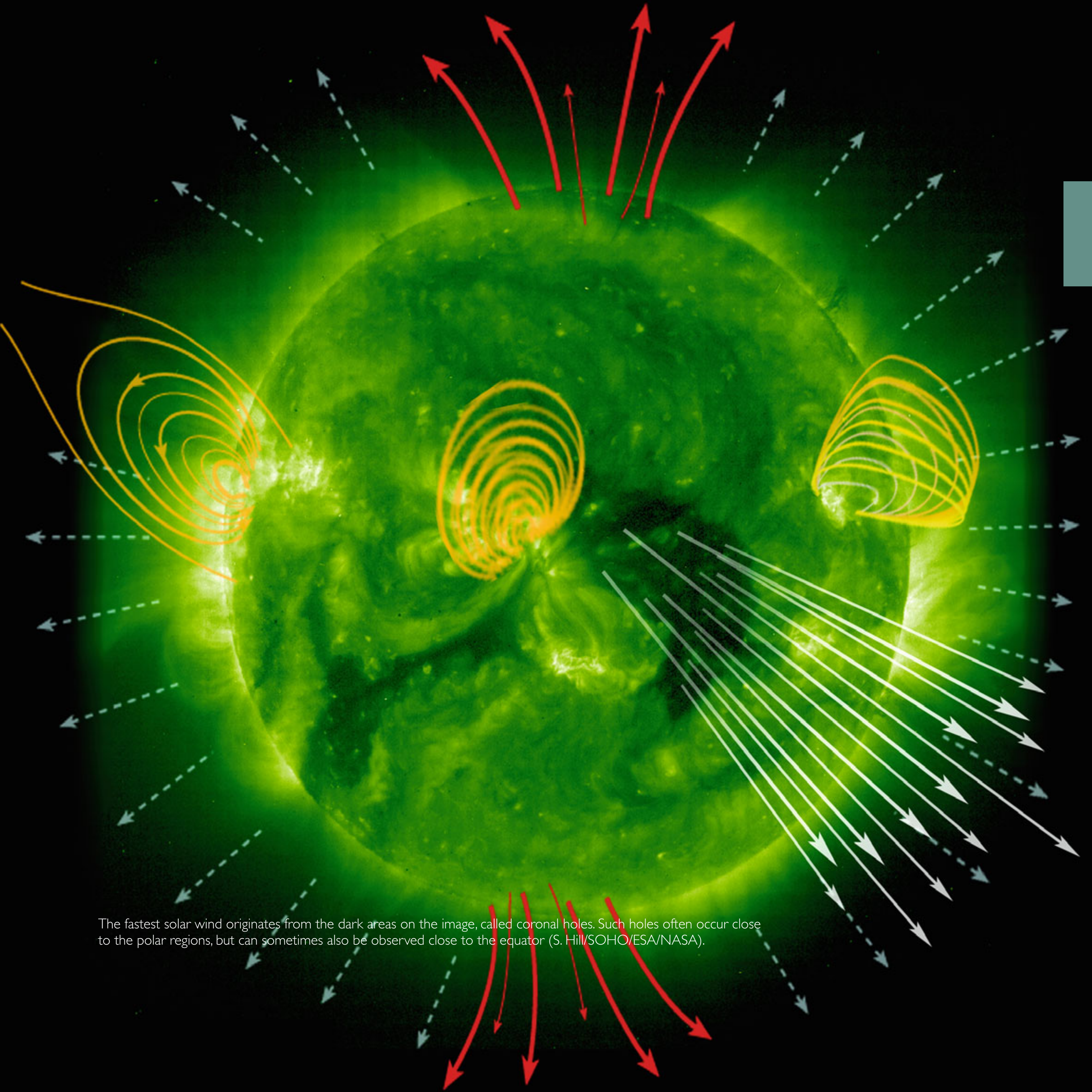
Luckily for us Earth has a protective magnetic field around itself that functions as an invisible shield against these particles. We call this shield the magnetosphere. Without it Earth's atmosphere would slowly be blown away from our planet and there would not be any life left here. The solar wind pushes the magnetosphere toward Earth on the dayside and stretches it out in a long tail on the night side. Sometimes there are strong gusts in the solar wind where the speed reaches more than 3 million km/h. This will cause the magnetosphere to shiver, and solar wind particles that have managed to enter inside the magnetosphere on the night side are ejected down toward the polar regions channeled along the magnetic field lines. Here they create auroras, as we will discuss later in the book.



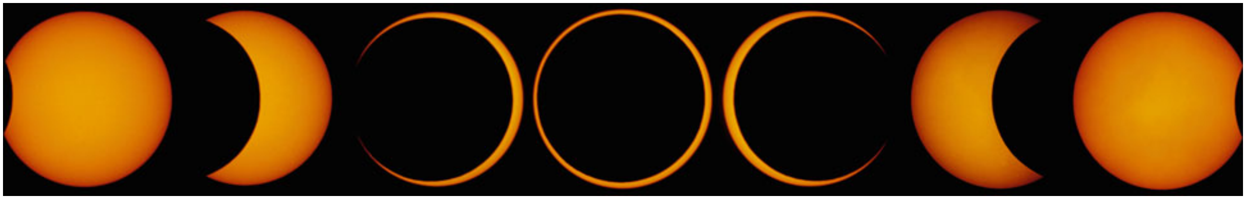
The solar wind is "blowing" out into space and pushing on Earth's magnetic field (NASA).



Sometimes when the Sun is "blowing" extra hard, Earth may be hit by a "wind gust" that will create extra strong northern lights (M. Brekke).



The fastest solar wind originates from the dark areas on the image, called coronal holes. Such holes often occur close to the polar regions, but can sometimes also be observed close to the equator (S. Hill/SOHO/ESA/NASA).



Time sequence showing the Moon glide across the solar disk on May 31, 2003. During this solar eclipse, the Moon was slightly farther away from Earth than normal, thus it was too small to cover the entire solar disk. Therefore, we can still see a thin ring of the Sun, and we call this an annular eclipse (A. Danielsen).

One of NASA's STEREO satellites captured this special "solar eclipse" (more accurately a Moon transit) on February 25, 2007, while the Moon was passing in front of the Sun. The Moon appears much smaller from the STEREO satellite since it was 4.4 times farther away from the Moon than we are (NASA).

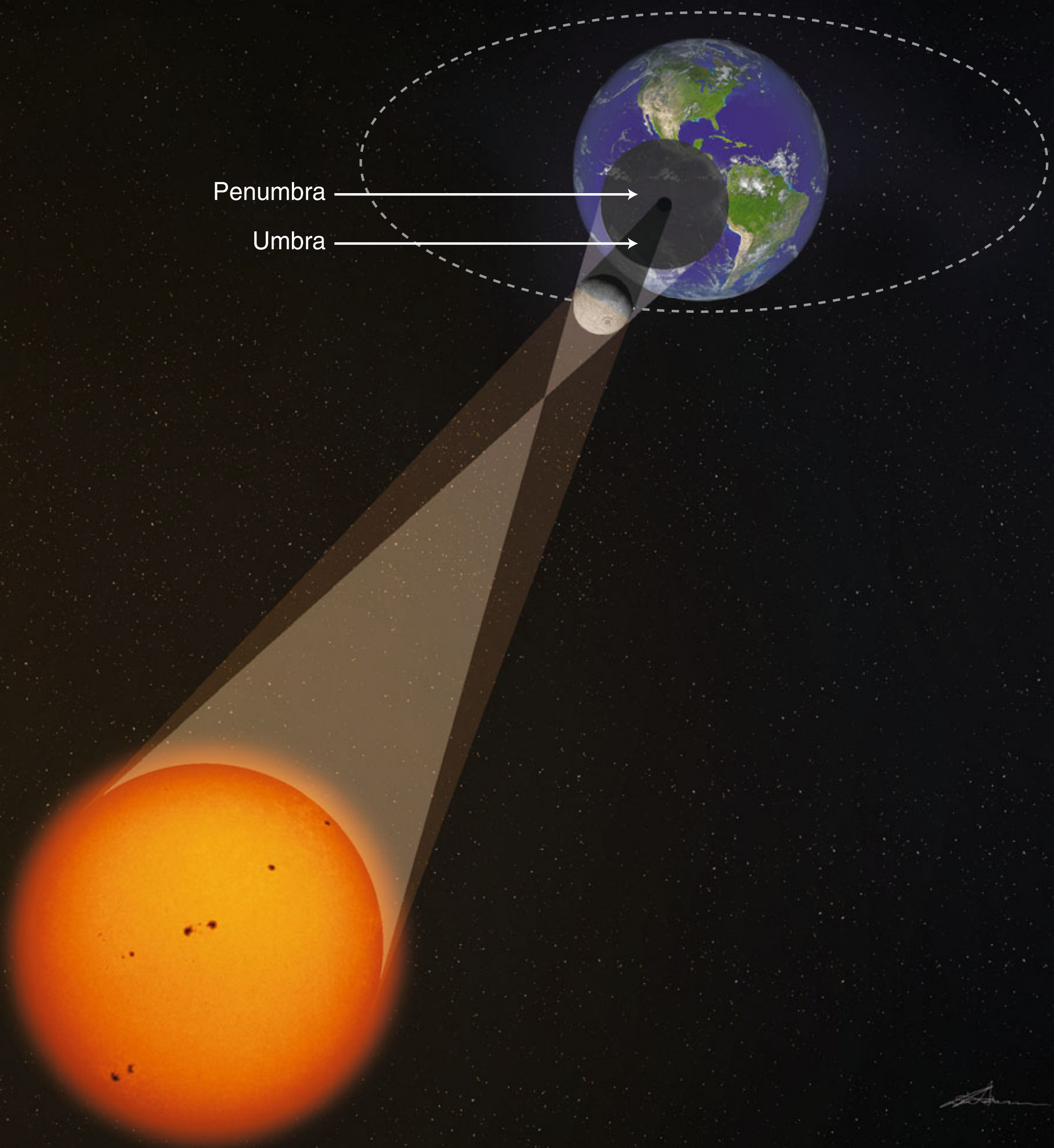
Solar Eclipses

The Moon orbits Earth, which in turn orbits the Sun. Thus, sometimes the Moon will be located between Earth and the Sun, and we will experience what we call a solar eclipse. By coincidence the Sun and the Moon appear to have the same size in the sky as seen from Earth.

The shadow of the Moon can sometimes reach the surface of Earth. There are three different types of solar eclipses: total, partial, and annular. During a total eclipse, the shape of the Moon covers the entire Sun, and one can see the chromosphere, prominences, and corona. The sky becomes dark, and one can see the brightest stars and planets. The eclipse will appear total if you are located within the umbra shadow. Annular eclipses occur when the Moon is a bit farther away; so its apparent size is too small to cover the entire Sun. A thin ring of the solar surface will be visible around the Moon. Partial eclipses occur where only a part of the Sun is covered by the Moon.

During a total solar eclipse, the Moon covers the entire solar disk. Only then the spooky-looking corona can be viewed. Here is a picture of the eclipse over Mongolia in 2008 (M. Druckmuller).

When Earth moves into the umbra from the Moon, one can observe a total eclipse. The umbra covers just a small area that will trace out a narrow band on Earth. Within this band, one will experience a total solar eclipse. Where the penumbra hits Earth, you will only see a partial eclipse (T. Abrahamsen/ARS).



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With advanced digital cameras placed on satellites in space, we can study different parts of the Sun (A. Lutkus).

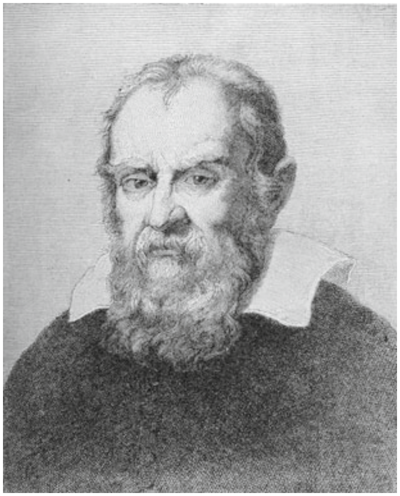
HOW DO WE STUDY THE SUN?

Galileo and His Telescope

In the summer of 1609, Galileo Galilei (1564–1642) learned about a new invention in the Netherlands that could make far objects appear closer. An optician had made the first telescope. Galileo bought some lenses from his local optician and built his own telescope. He improved this after just a few months and pointed it toward the sky. He made some important new discoveries, such as craters and mountains on the Moon, the phases of Venus, and the moons around Jupiter. When he pointed the telescope toward the Sun in 1610, he noticed dark spots on the surface. He studied the spots over months and noticed how they moved each day.

Was he the first to observe sunspots? Maybe not. The English astronomer Thomas Herriot was probably somewhat earlier, and we know of his drawings of sunspots, but he never published them as Galileo did. Some people argued that the spots were located between the Sun and Earth. Galileo, however, argued that the spots were part of the Sun and that the Sun rotated around its own axis. Most probably the ancient Chinese astronomers had observed large sunspots with the naked eye 1,500 years ago.

The Galileoscope is a copy of Galileo's first telescope. It was made to be put together by students to let them experience what Galileo observed 400 years ago. More modern lenses are also included. More information about the telescope can be found on www.galileoscope.org.



Galileo Galilei was the first human to point a telescope toward the night sky (Sarah K. Bolton/ Justus Sustermans).

Galileo's original drawings of sunspots he observed through his telescope. He almost became blind in both eyes doing this (Galileo Project, Rice University/O. Gingrich).

Large Telescopes Analyzing the Light from the Sun

Since Galileo pointed his telescope toward the Sun, larger and larger telescopes have been built to observe the Sun and the night sky. In modern times, they were often built on top of mountains where it was clearer and there were less disturbances in the atmosphere, providing sharper images of the Sun. More recently, the best telescopes have been located on the tops of islands with tall mountains. Telescopes on Hawaii, Tenerife, and LaPalma are almost always above the clouds and can study the Sun most days.

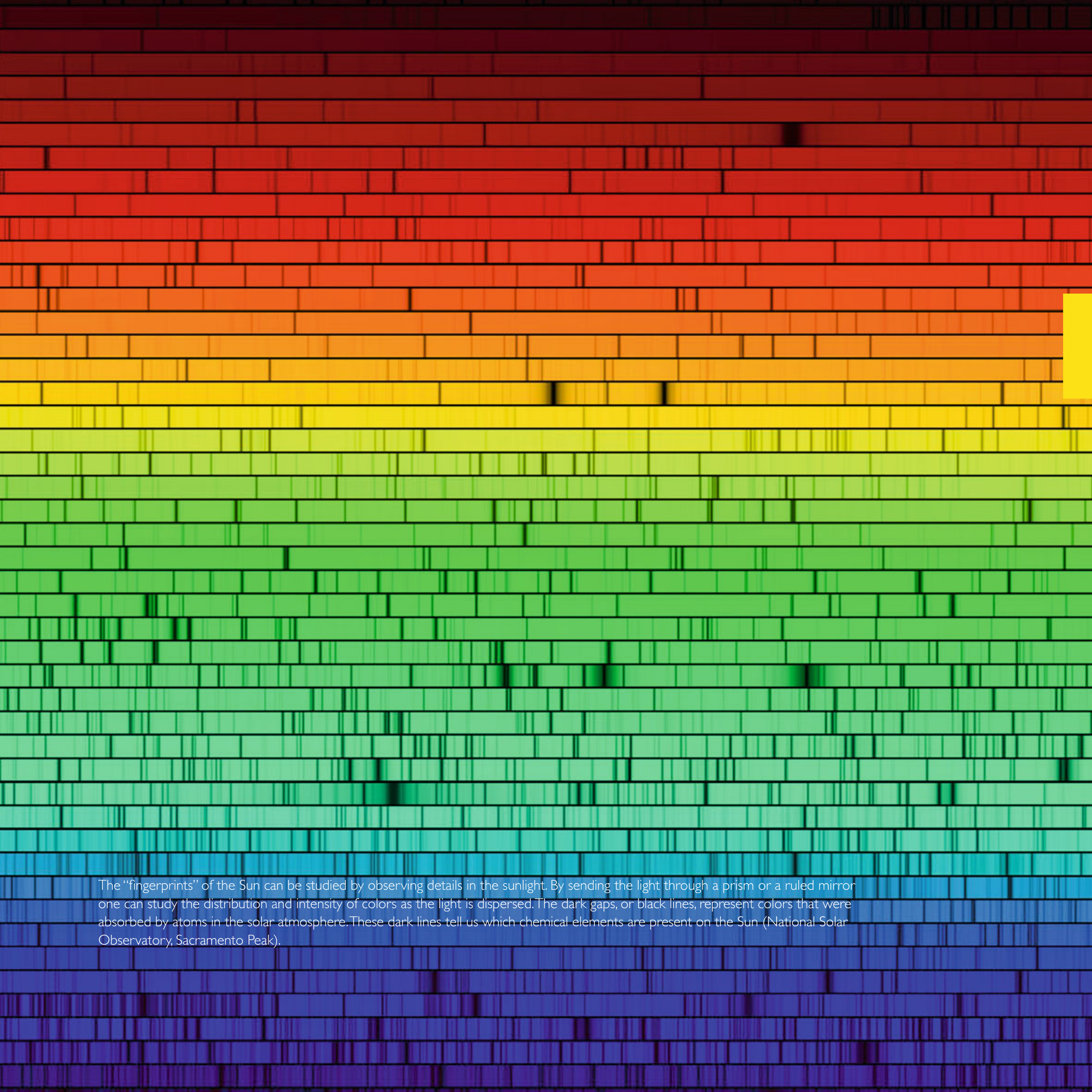
Maybe the best telescope in the world is the Swedish telescope at LaPalma. The telescope can see details down to 70 km on the surface of the Sun. This is quite impressive when you know the Sun is 150 million km away. In fact this telescope would be able to read a license plate on a car 100 km away. The police would probably love to have such a telescope!

The Sun emits both visible and "invisible" light, such as ultraviolet light (UV) and X-rays. It is mainly the visible light that penetrates the atmosphere and reaches the ground. UV and X-rays are blocked by Earth's atmosphere.

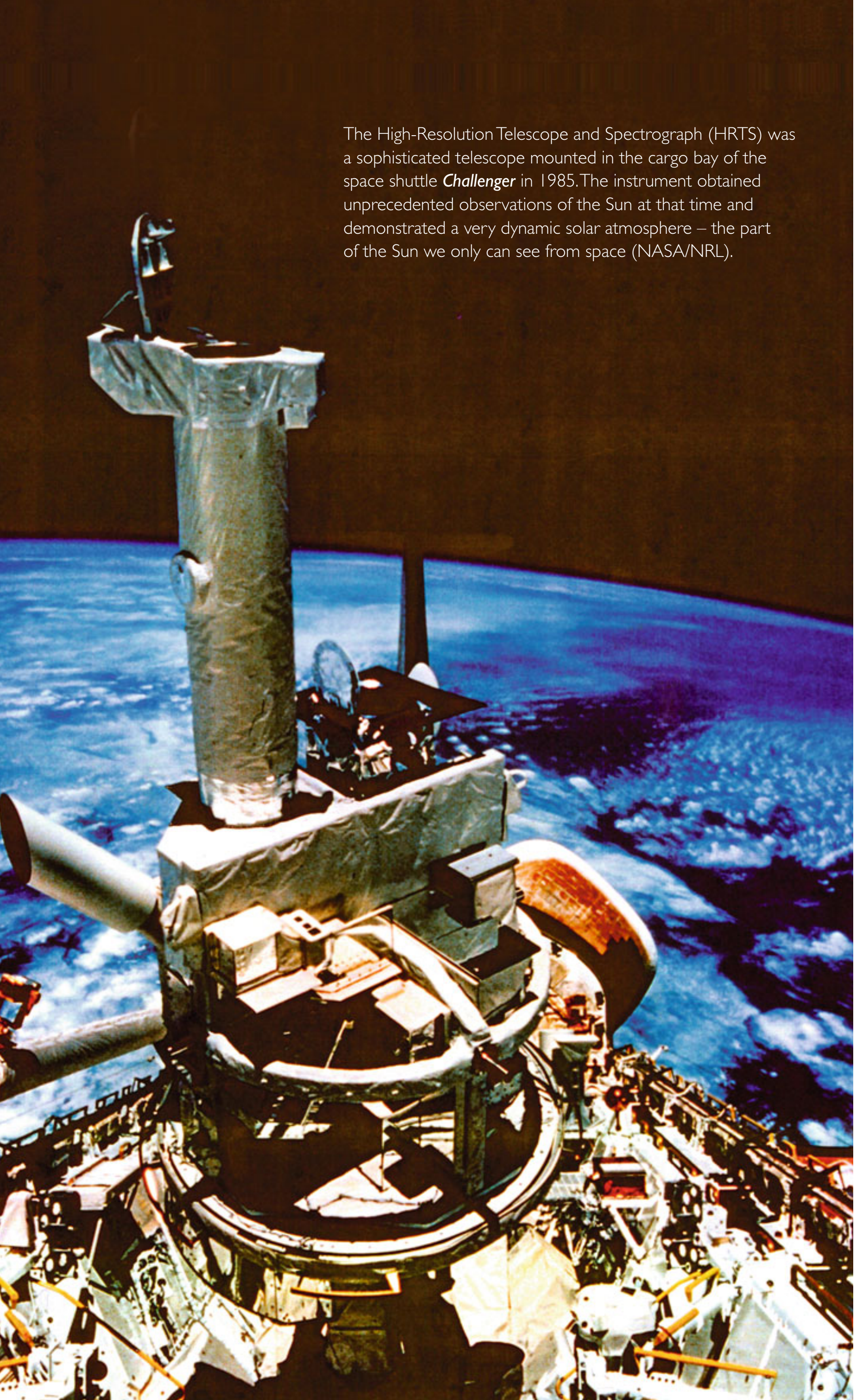
Large telescopes observe the visible light from the Sun and feed the light into special instruments that split the light into its individual colors. We can then study the distribution of the colors and their intensities where dark lines provide information about the chemical elements present on the Sun. Thus, we can determine what the Sun is made of without having to go there.

Big Bear Observatory is located at Big Bear Lake in California.

The Swedish solar observatory at LaPalma is regarded by many as the best in the world. Most modern telescopes are located on the tops of islands far out in the ocean. Here they are above the clouds most of the time (Royal Swedish Academy of Sciences).



The "fingerprints" of the Sun can be studied by observing details in the sunlight. By sending the light through a prism or a ruled mirror one can study the distribution and intensity of colors as the light is dispersed. The dark gaps, or black lines, represent colors that were absorbed by atoms in the solar atmosphere. These dark lines tell us which chemical elements are present on the Sun (National Solar Observatory, Sacramento Peak).



The High-Resolution Telescope and Spectrograph (HRTS) was a sophisticated telescope mounted in the cargo bay of the space shuttle ***Challenger*** in 1985. The instrument obtained unprecedented observations of the Sun at that time and demonstrated a very dynamic solar atmosphere – the part of the Sun we only can see from space (NASA/NRL).

The Sun Observed from Space

After World War II, the United States confiscated German V2 rockets and used them for science. Instruments were for the first time launched outside the atmospheric layers blocking the UV radiation from the Sun. On October 10, 1946, the first successful launch took place, and the rocket reached an altitude of 175 km. Such sounding rockets were used for many years to study UV and X-rays from the Sun. However, each launch only provides a few minutes of observing time. Today we use advanced telescopes and instruments mounted on satellites in space. They can observe the Sun 24 h a day for many years without problems with clouds or the atmosphere. These movements of air masses in the atmosphere are what make the stars twinkle in the sky.

Skylab was the first U S space station and orbited Earth from 1973 to 1979. A large platform mounted on the outside of ***Skylab*** included several solar telescopes, which provided a number of revolutionary pictures of the Sun's hot corona (NASA).

A V-2 rocket launched from White Sands in New Mexico in the United States (NRL).

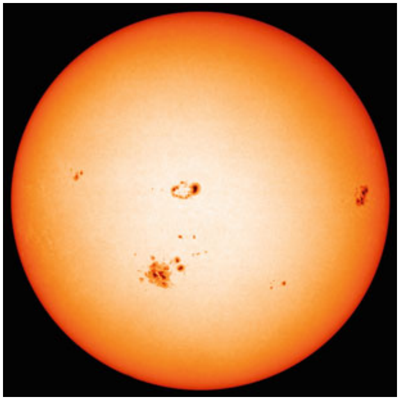
SOHO and SDO

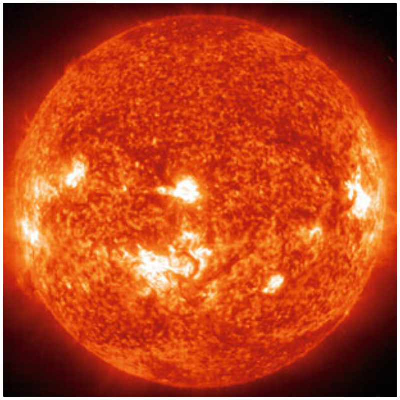
Many of the most spectacular images of the Sun come from solar telescopes orbiting in space, such as the Solar and Heliospheric Observatory (SOHO). SOHO was launched December 2, 1995, and is located 1.5 million km from Earth (four times the distance to the Moon), between Earth and the Sun. From this vantage point, SOHO could study the Sun day and night. From space, we can study layers of the solar atmosphere that we cannot see from the ground. The reason is that most of the radiation from the chromosphere and the corona is blocked by Earth's atmosphere.

The Solar Dynamics Observatory (SDO) is a new NASA satellite launched in 2010. SDO takes images with four times higher resolution than HD TV and pictures every 10 s in each wavelength it observes. It is designed to help us understand the dynamic processes on the Sun and the Sun's influence on Earth.

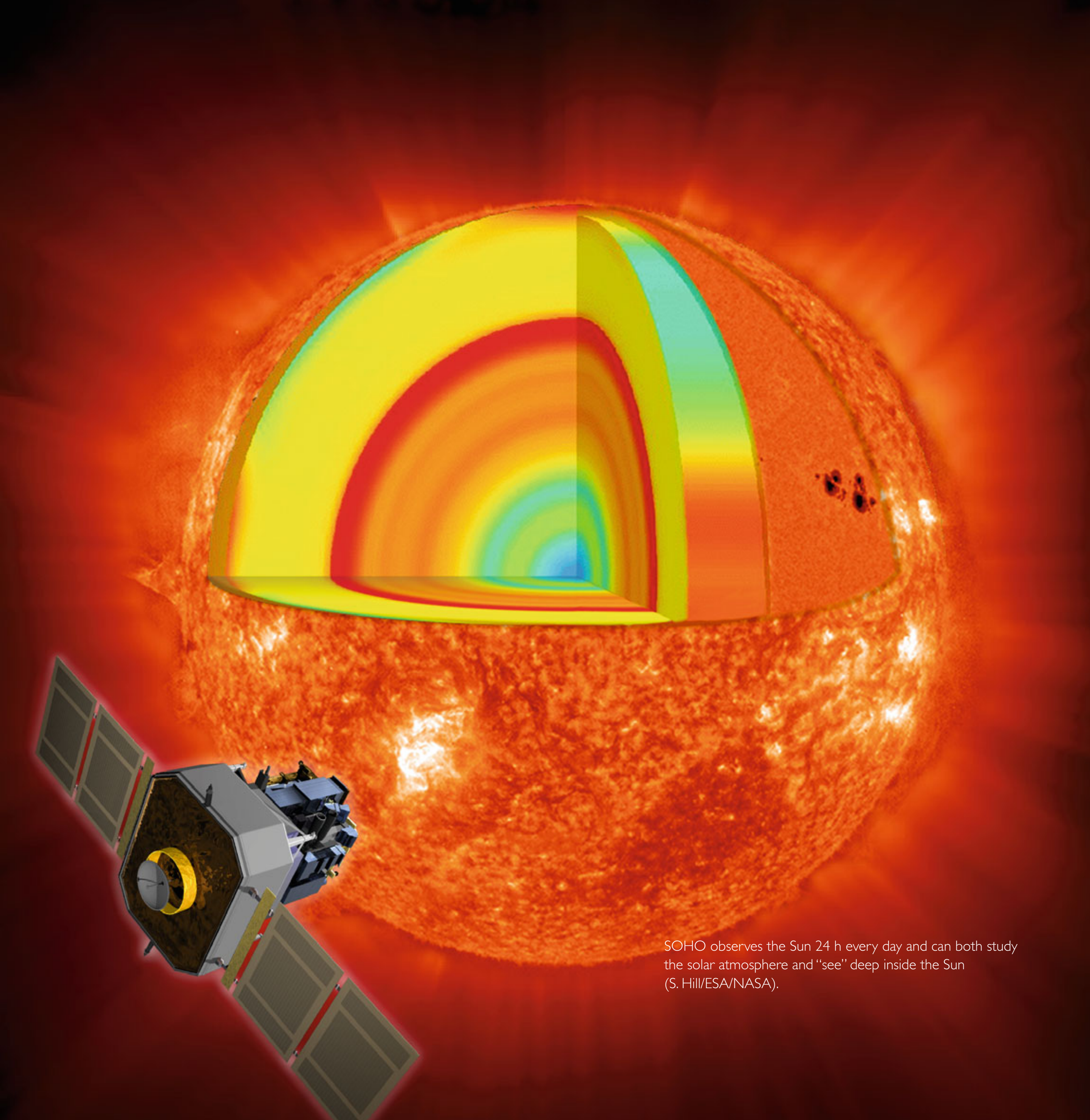
Below you can see two images of the Sun. The left one is taken with a camera observing in visible light. The Sun looks just like how we see it with the naked eye. The image to the right is taken the same day and looks very different. It was taken with an ultraviolet camera. Ultraviolet radiation is invisible to our eyes. However, special instruments can detect this radiation. What we see in this image is the Sun's chromosphere – a layer of hot gas above the visible surface. Here the bright areas are called active regions with enhanced ultraviolet emission.

Solar Dynamics Observatory was launched in 2010 (NASA).

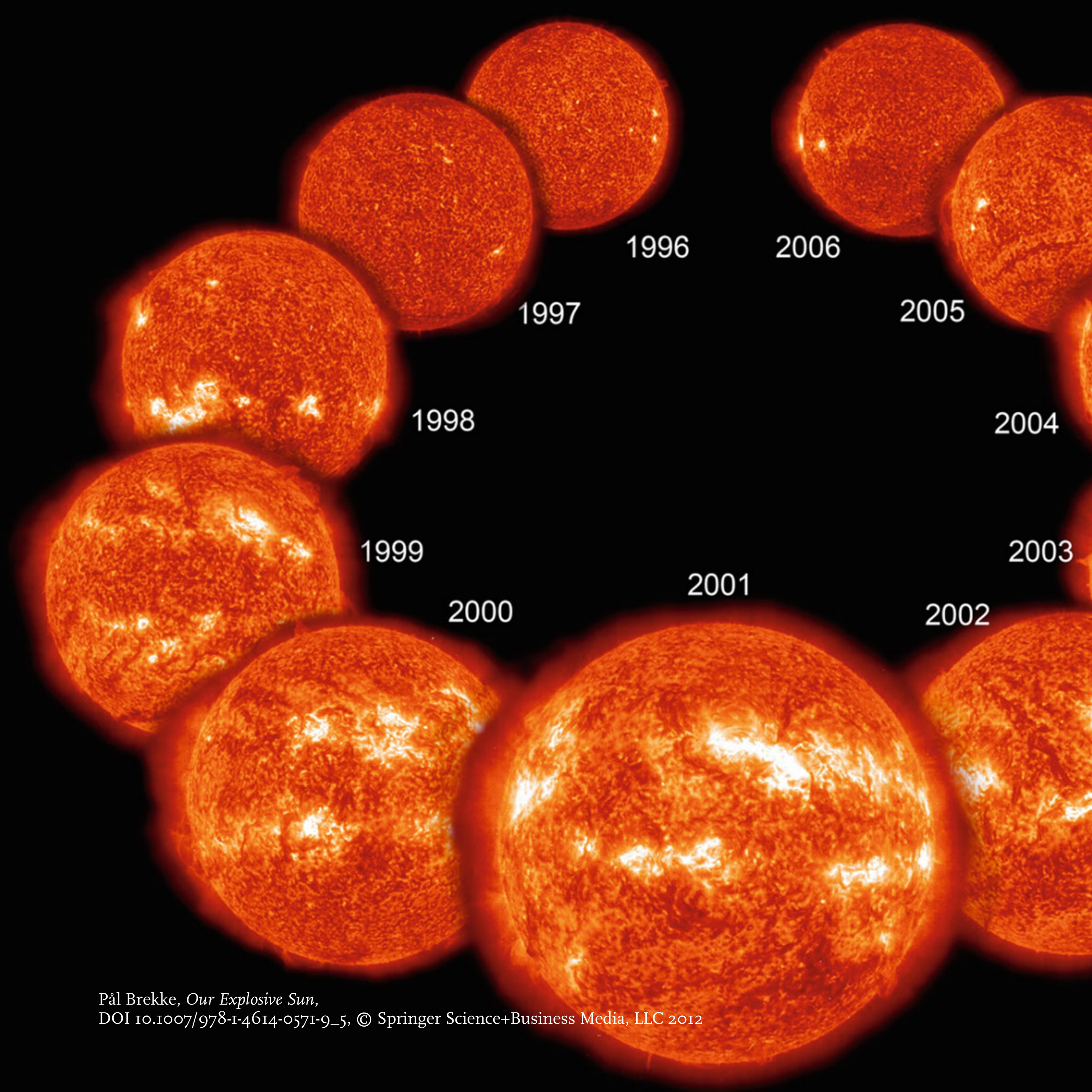




The Sun observed with a camera using visible light (left); you can see the surface and sunspots. The image to the right is taken with a camera sensitive to ultraviolet light, which lets us see the Sun's outer atmosphere (ESA/NASA).



SOHO observes the Sun 24 h every day and can both study the solar atmosphere and "see" deep inside the Sun (S. Hill/ESA/NASA).



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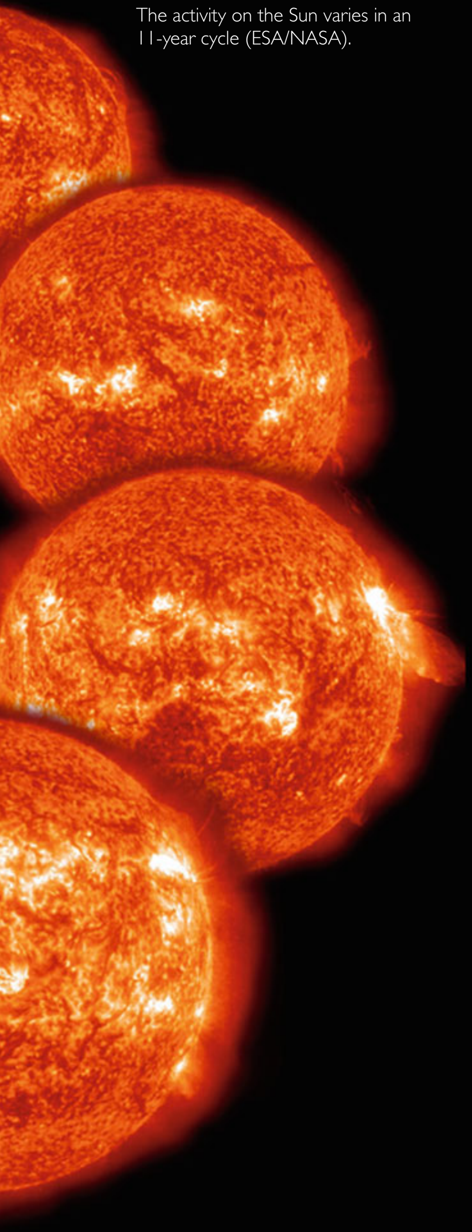


The activity on the Sun varies in an 11-year cycle (ESA/NASA).

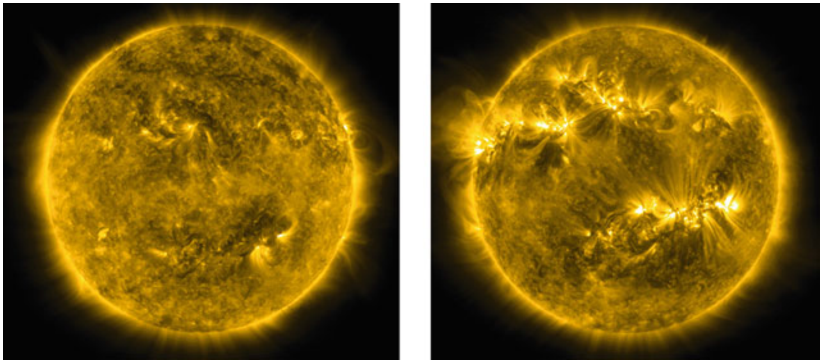
THE SUN: A VARIABLE STAR

The Sun: A Variable Star

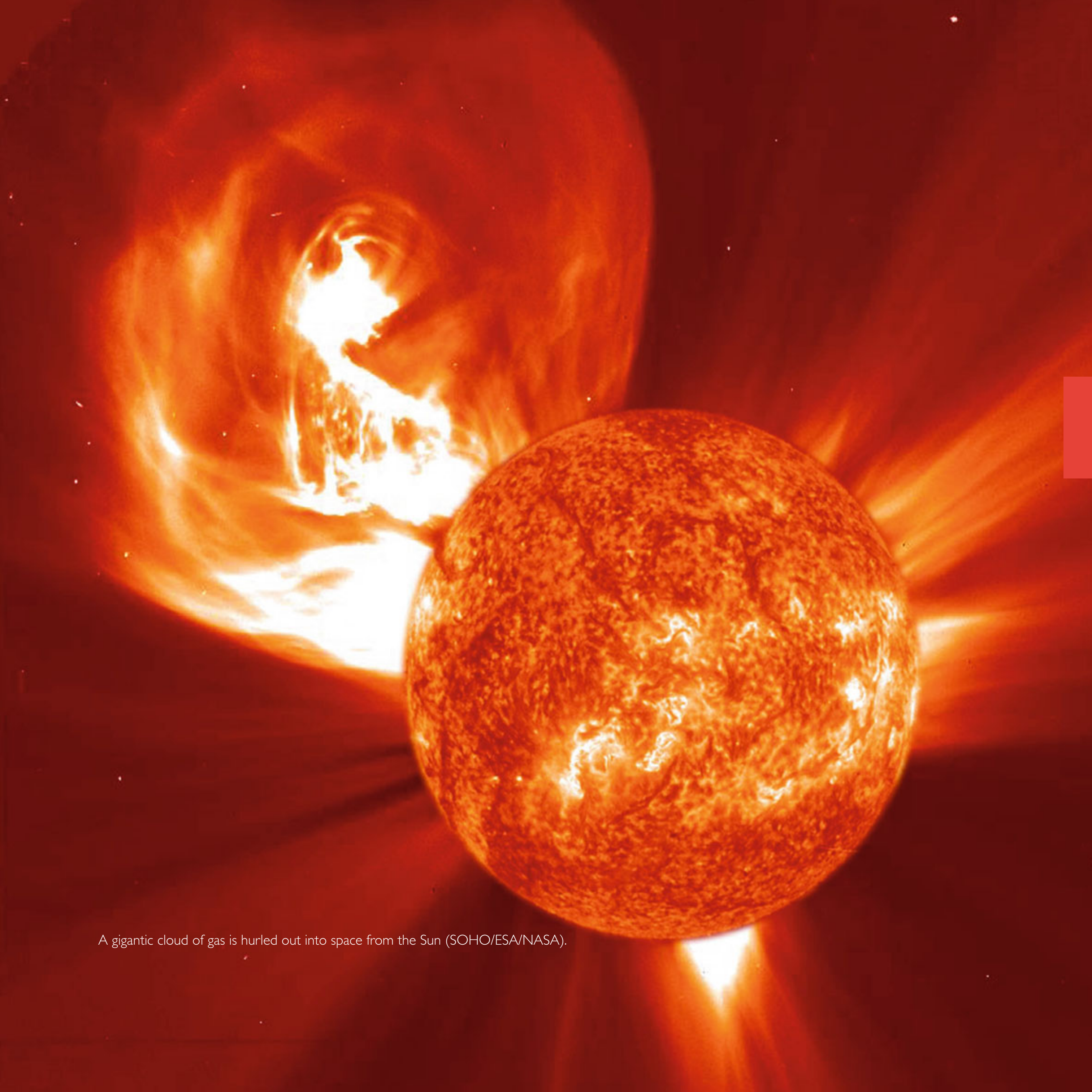
Seen from Earth with the naked eye, the Sun appears to be quite static and calm, a yellow disk in the sky. However, the Sun is a very variable and stormy star and contributes much more than just heat and light. It is the source of auroras and can have a great impact on our technology-based society. It also affects the climate, since the amount of energy is varying. That is why it is so important to increase our knowledge about the Sun – our life-supporting star.

With new and more sophisticated observatories on the ground and in space, we can learn more about its many secrets.

For us here on Earth, the Sun appears to be a calm, yellow sphere gliding across the sky without changing. Here we see a sunrise at 4.30 a.m. outside the islands of Lyngør, Norway (P. Brekke).



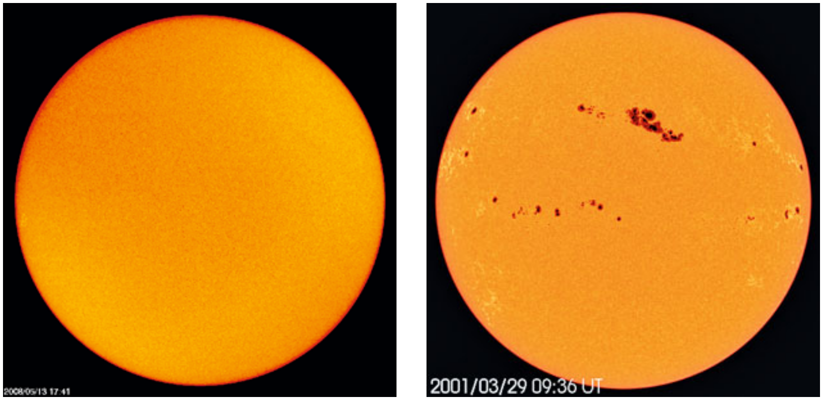
The Sun observed close to solar minimum (*left*) and near solar maximum (*right*). Notice that here we see many more bright and intense areas when the Sun is active. (SDO/NASA).



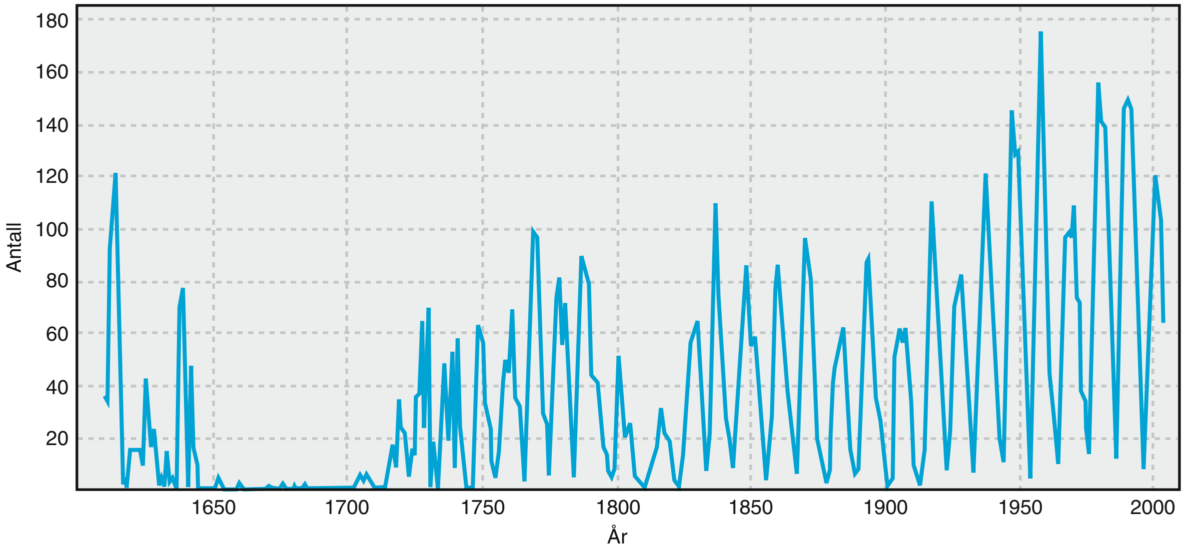
A gigantic cloud of gas is hurled out into space from the Sun (SOHO/ESA/NASA).

Sunspot Cycle

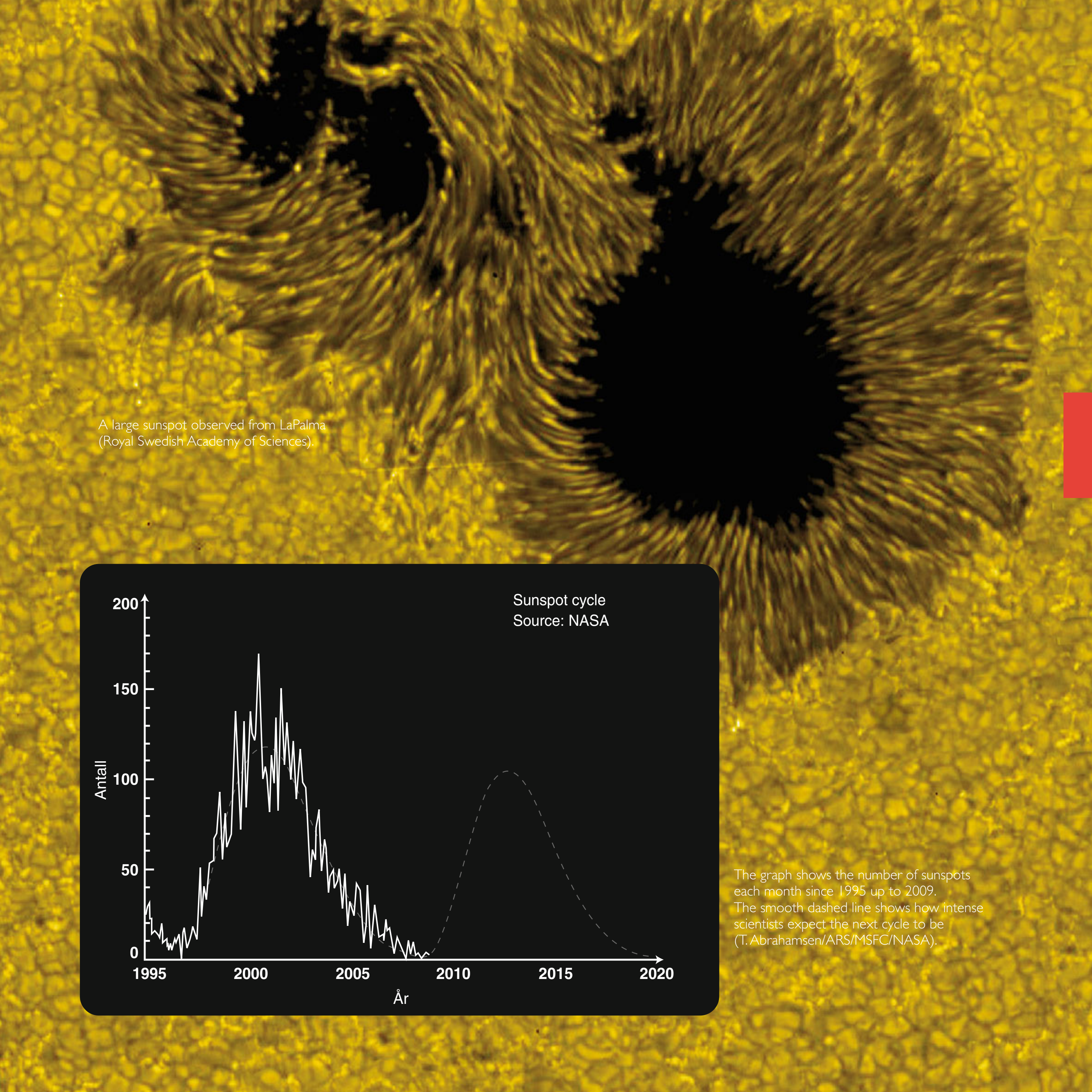
Every 11 years or so the Sun goes through a period we call "solar maximum," where there are many large sunspots. About 5 years later, the Sun will enter "solar minimum," where there are few or no spots. By keeping track of the number of sunspots, we can follow the pulse of the Sun and how the magnetic forces and number of storms are changing. We have a good record of sunspots starting in 1610, when Galileo used his telescope.



Some days there are no visible sunspots; other days there can be many large ones (SOHO/ESA/NASA).



This graph plots 400 years of data on the number of sunspots seen each year, showing the rhythmic rise and fall of solar activity. The 11-year cycle is obvious (T. Abrahamsen/ARS).



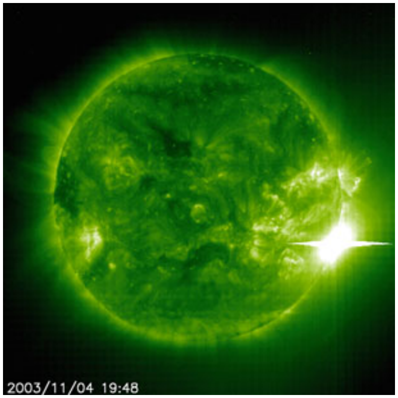
A large sunspot observed from LaPalma (Royal Swedish Academy of Sciences).

The graph shows the number of sunspots each month since 1995 up to 2009.
The smooth dashed line shows how intense scientists expect the next cycle to be (T. Abrahamsen/ARS/MSFC/NASA).

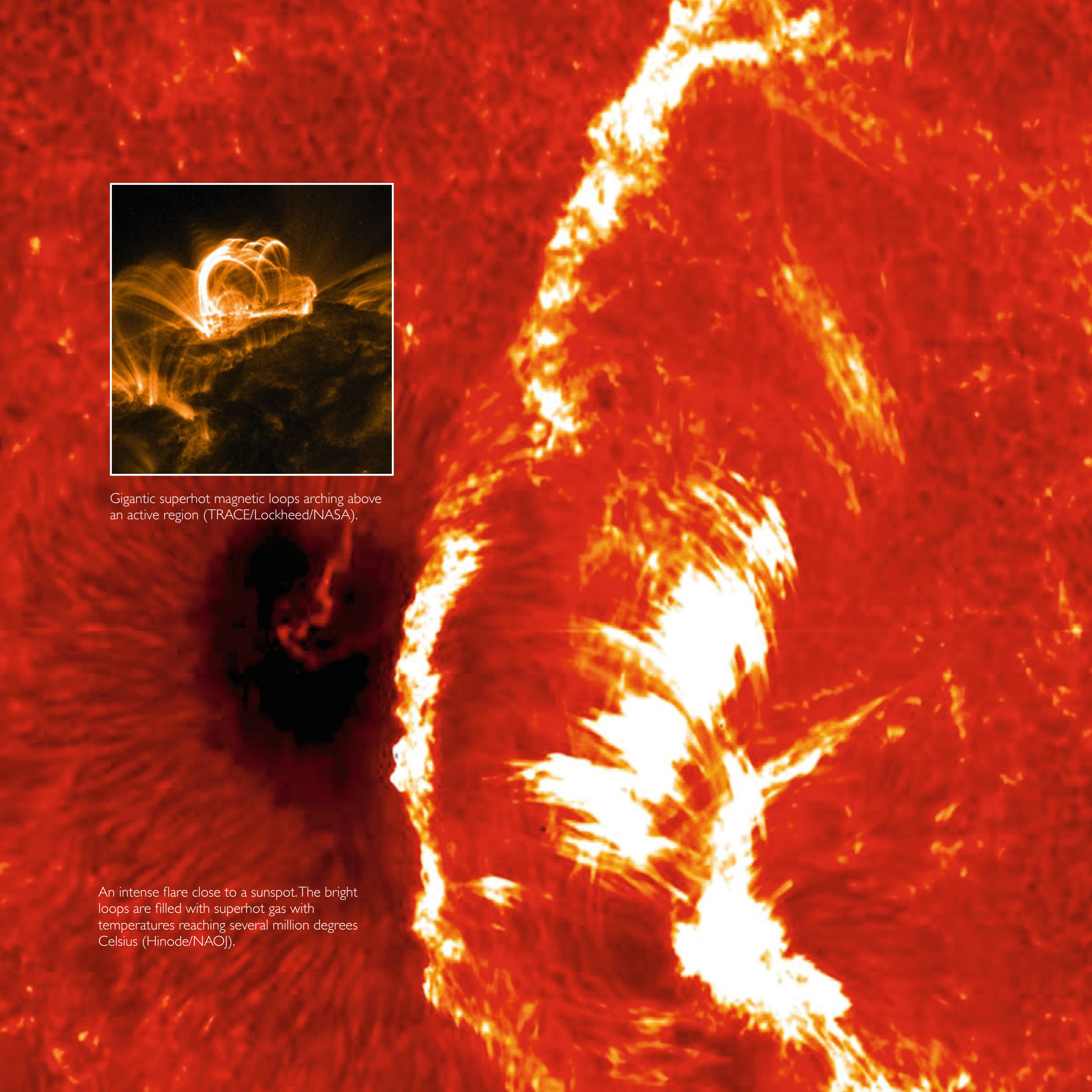
Explosions on the Sun

The magnetic field in large active regions on the Sun often gets unstable. This can result in violent explosions in the solar atmosphere – called "flares." A flare can release in seconds energy corresponding to several billion megatons of TNT. During such explosions, the gas is heated to 20 million degrees Celsius. This superheated gas will emit large amounts of UV radiation and X-rays. The radiation travels with the speed of light and hits Earth's atmosphere 8 min and 20 s later. Luckily, this hazardous radiation is blocked by protective gases in our atmosphere such as ozone. As will be described later such explosions can affect radio and satellite communication.

An artistic illustration of a solar flare igniting. Sometimes magnetic field lines with opposite directions can reconnect, and large amounts of energy will be released in the form of light and heat (MSFC/NASA).



A strong explosion (flare) observed near the solar limb in 2003 (SOHO/ESA/NASA).

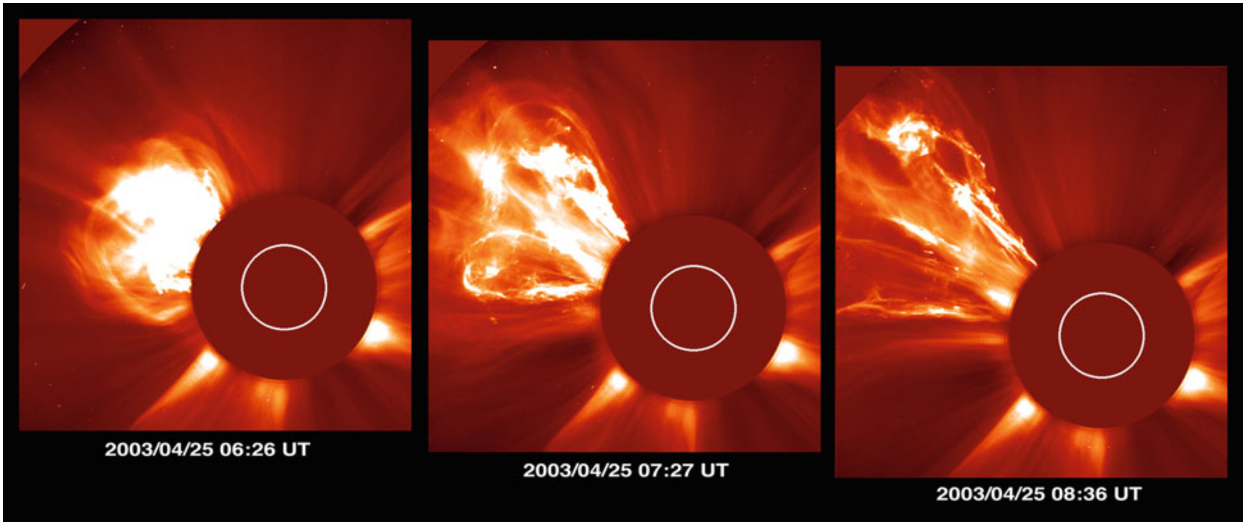


Gigantic superhot magnetic loops arching above an active region (TRACE/Lockheed/NASA).

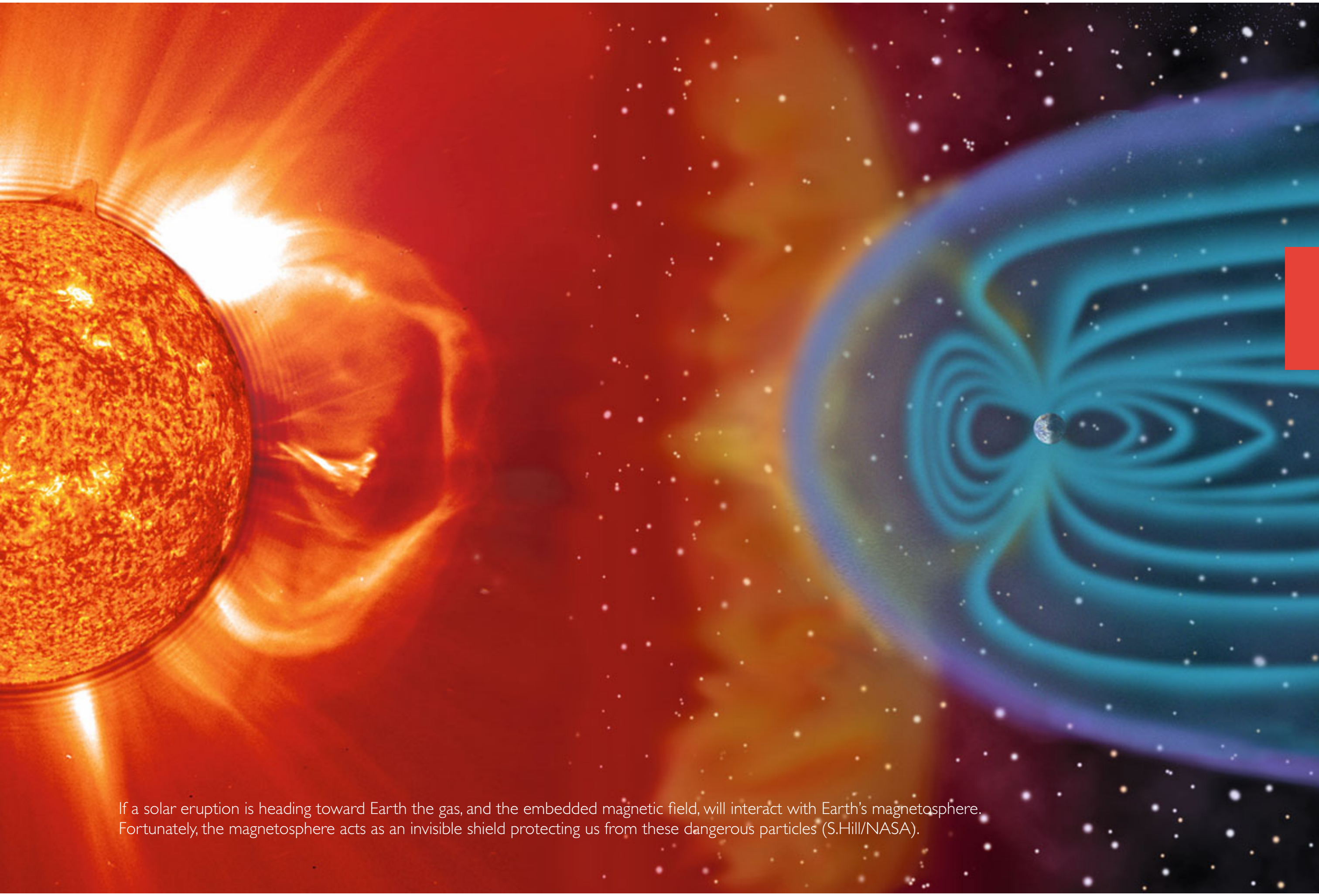
An intense flare close to a sunspot. The bright loops are filled with superhot gas with temperatures reaching several million degrees Celsius (Hinode/NAOJ).

Gas Eruptions on the Sun

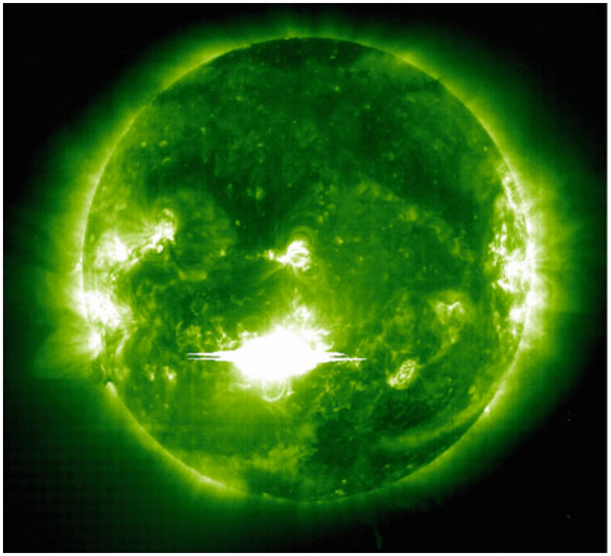
Sometimes large prominences can erupt, and large amount of gas and magnetic fields are ejected out in space. The largest eruptions eject several billion tons of particles corresponding to 100,000 large battleships. Such eruptions are called coronal mass ejections, CMEs for short. The bubble of gas will expand out into space and can reach velocities up to 8 million km/h. Still, it would take almost 20 h before it reaches Earth. Usually the solar wind spends 3 days on this journey. If such an eruption is directed toward Earth, the particles will be deflected by our magnetosphere. The cloud of gas will push and shake Earth's magnetic field and generate a kind of "storm" that we call a geomagnetic storm. Under such storms, we will experience strong auroras.

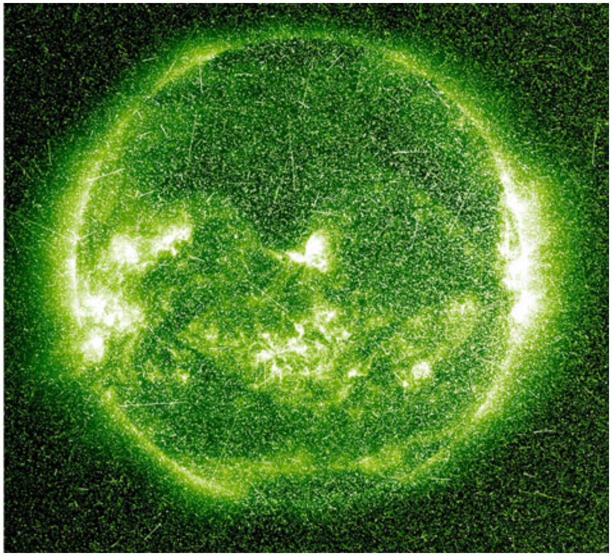


A coronal mass ejection (weighing a billion tons of gas) is launched out into space. The images were taken by the LASCO instrument on SOHO. A small disk inside the telescope blocks the bright light from the solar disk, creating an artificial eclipse (SOHO/ESA/NASA).



If a solar eruption is heading toward Earth the gas, and the embedded magnetic field, will interact with Earth's magnetosphere. Fortunately, the magnetosphere acts as an invisible shield protecting us from these dangerous particles (S.Hill/NASA).





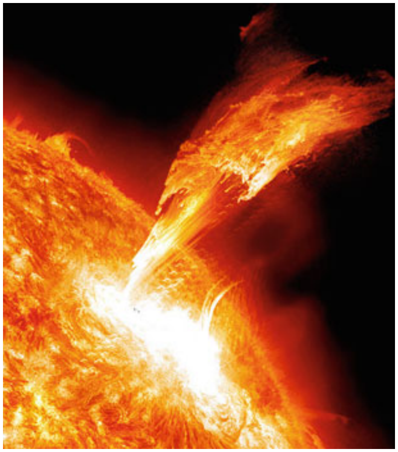
The left image shows an intense flare near the central part of the Sun. Sometimes large amounts of high-energy particles are accelerated toward Earth from explosive events on the Sun. In the right image, they produce a lot of white noise (SOHO/ESA/NASA).

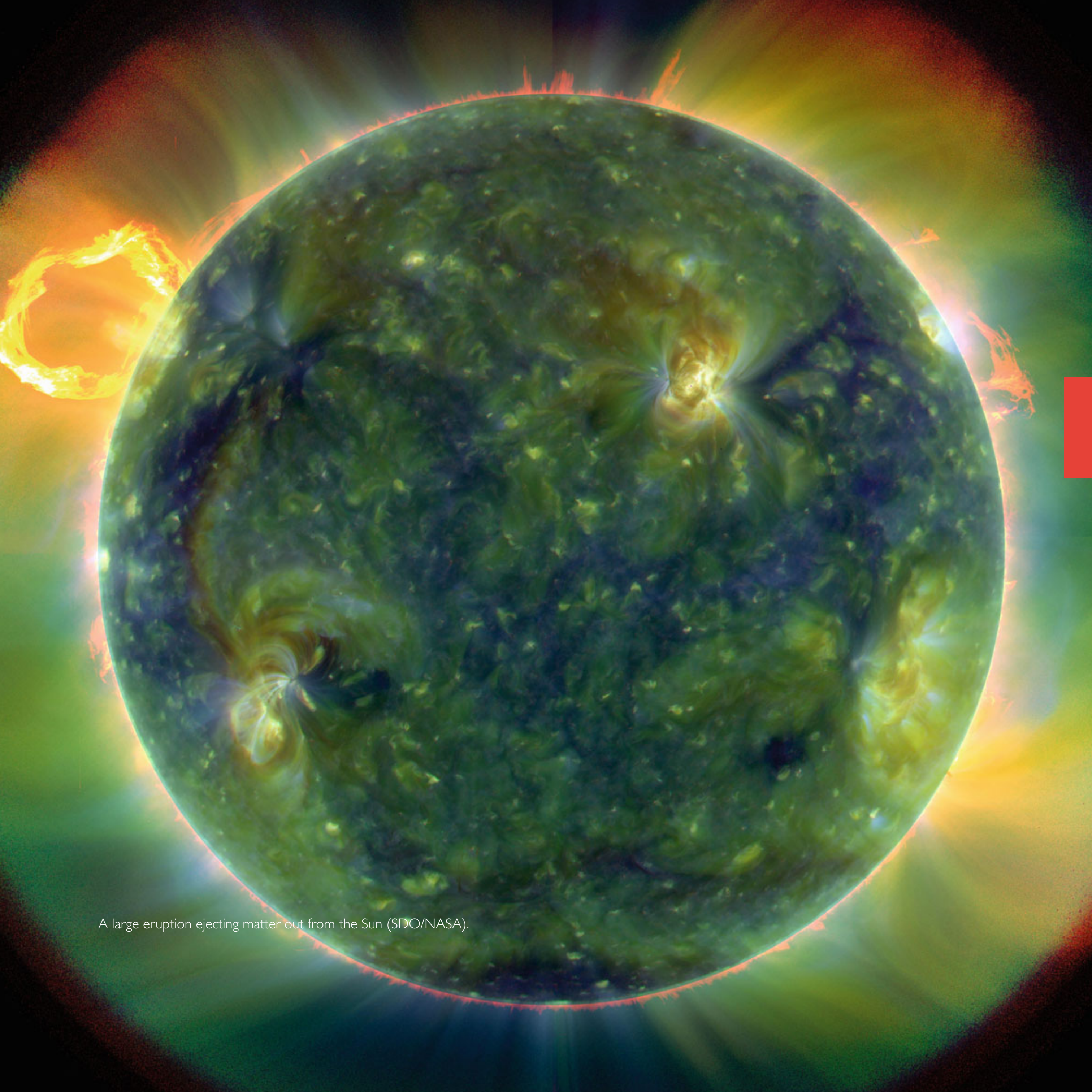
Particle Showers from the Sun

A few times explosions or eruptions will accelerate large amount of particles that travel at almost the speed of light. Such showers of particles consist mostly of protons, which take less than an hour to reach Earth. The protons have such high speed and energy that they can penetrate satellites and spacecraft. Thus, they can damage vital electronic equipment. They can also destroy the quality of images and scientific data from those satellites that are surveying the Sun, as shown in the picture above.

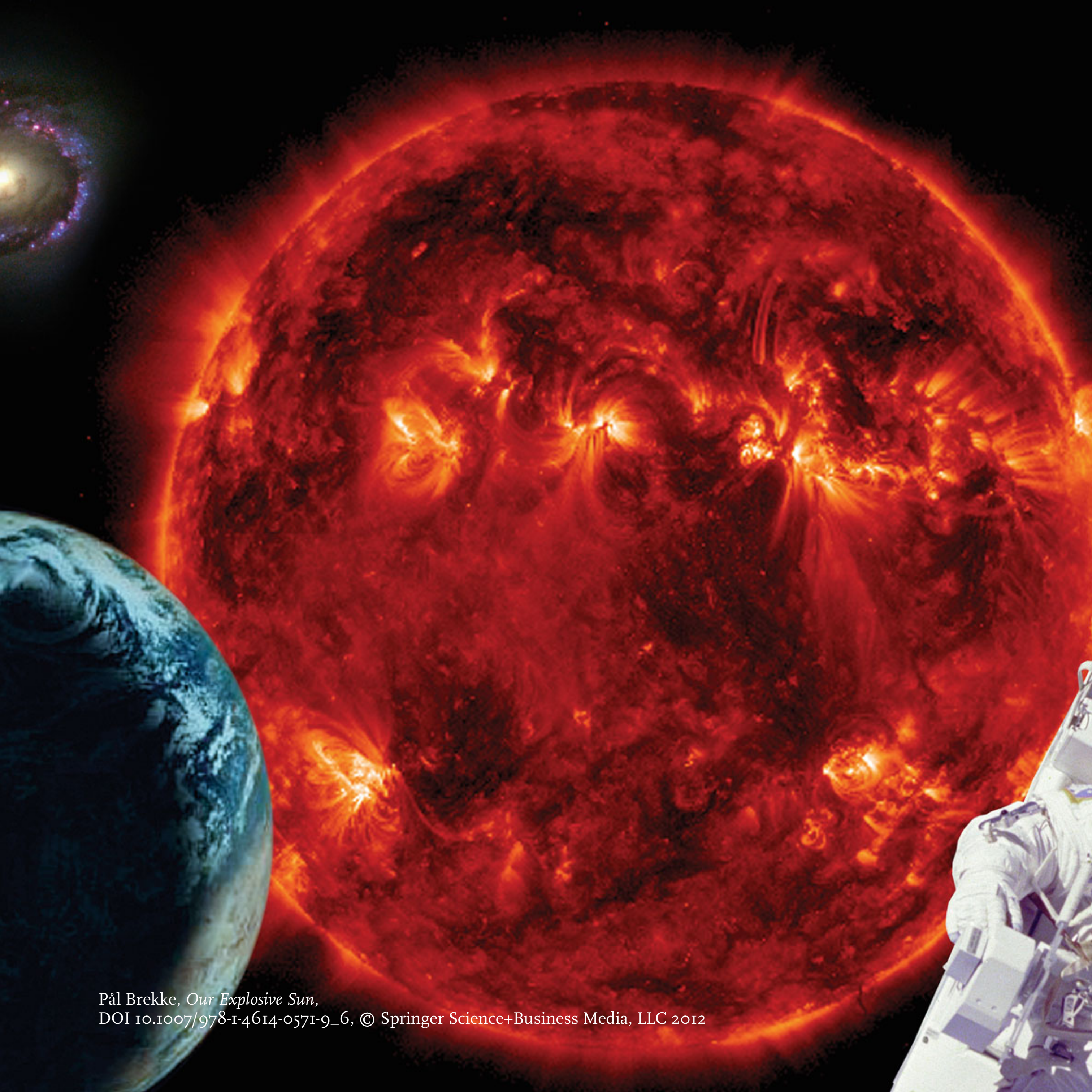
The particles "blind" the digital cameras, and we see a large amount of noise in the images. Many satellites have been damaged from "hailstorms" of protons from the Sun. These protons can also harm humans in space. Here on Earth we are well protected from such storms. Our magnetosphere prevents the particles from reaching the ground.

A strong flare observed with SDO on March 7, 2011. Earlier scientists believed only flares triggered energetic particle showers. Today we know that CMEs may also produce high-energy particles (SDO/NASA).





A large eruption ejecting matter out from the Sun (SDO/NASA).



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The polar regions of the planets "glow" as a result of solar storms, which can also harm humans in space (NASA).

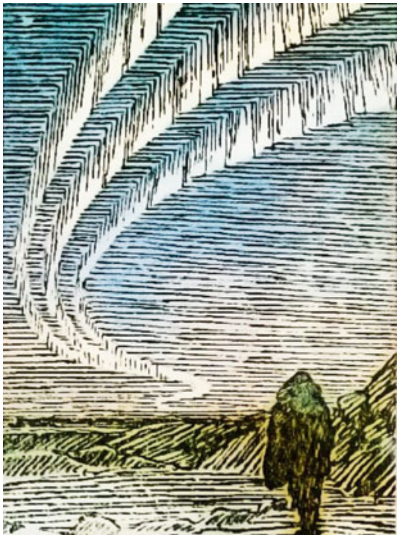
THE NORTHERN LIGHTS AND SPACE WEATHER

The Northern Lights: Myths

In ancient times, people looked at the northern lights as an omen of war, disaster, or plagues. Often children were brought inside, and many people were fearful. The aurora has made an especially deep impression on Scandinavian cultures. There have been many names for it through the years. The scientific name is Aurora Borealis, which in Latin means something like "the red dawn of the North." But why, since we often think of green light when we see it? It was Galileo who first used this expression. During very strong solar storms, the aurora can sometimes be seen as far south as Italy and often with a reddish color.

The northern lights over Bear Lake in Alaska (US Air Force).

Wooden carving by the Norwegian explorer Fritjof Nansen (F. Nansen).



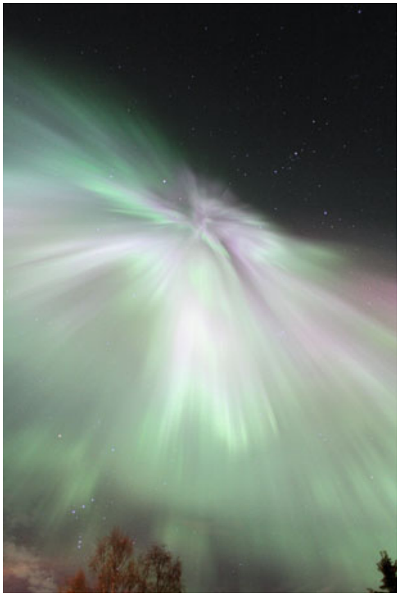
In previous times, many people believed if they waved a white handkerchief, the aurora would be more intense (U. Dreyer).

Early Science: Kristian Birkeland

There have been hundreds of stories and theories about the northern lights, but for thousands of years, nobody understood there was a connection with the Sun.

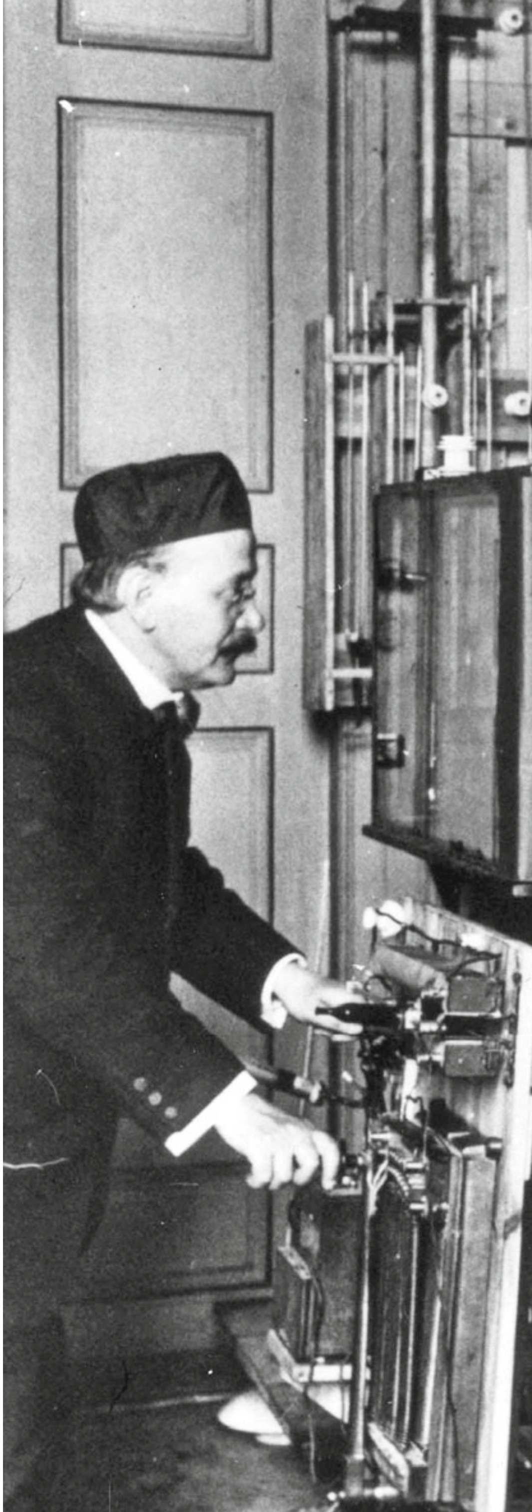
When the eccentric Norwegian scientist Kristian Birkeland (1867–1917) built his own model of our world in a glass box and added a magnetic field around it, he was the first to prove that particles from the Sun could generate the northern lights. He also proved that a similar light phenomenon would appear simultaneously near the southern polar regions. Thus, polar light is maybe a better name. Birkeland's theory could not be confirmed until we could launch rockets and satellites into space about 60 years later.

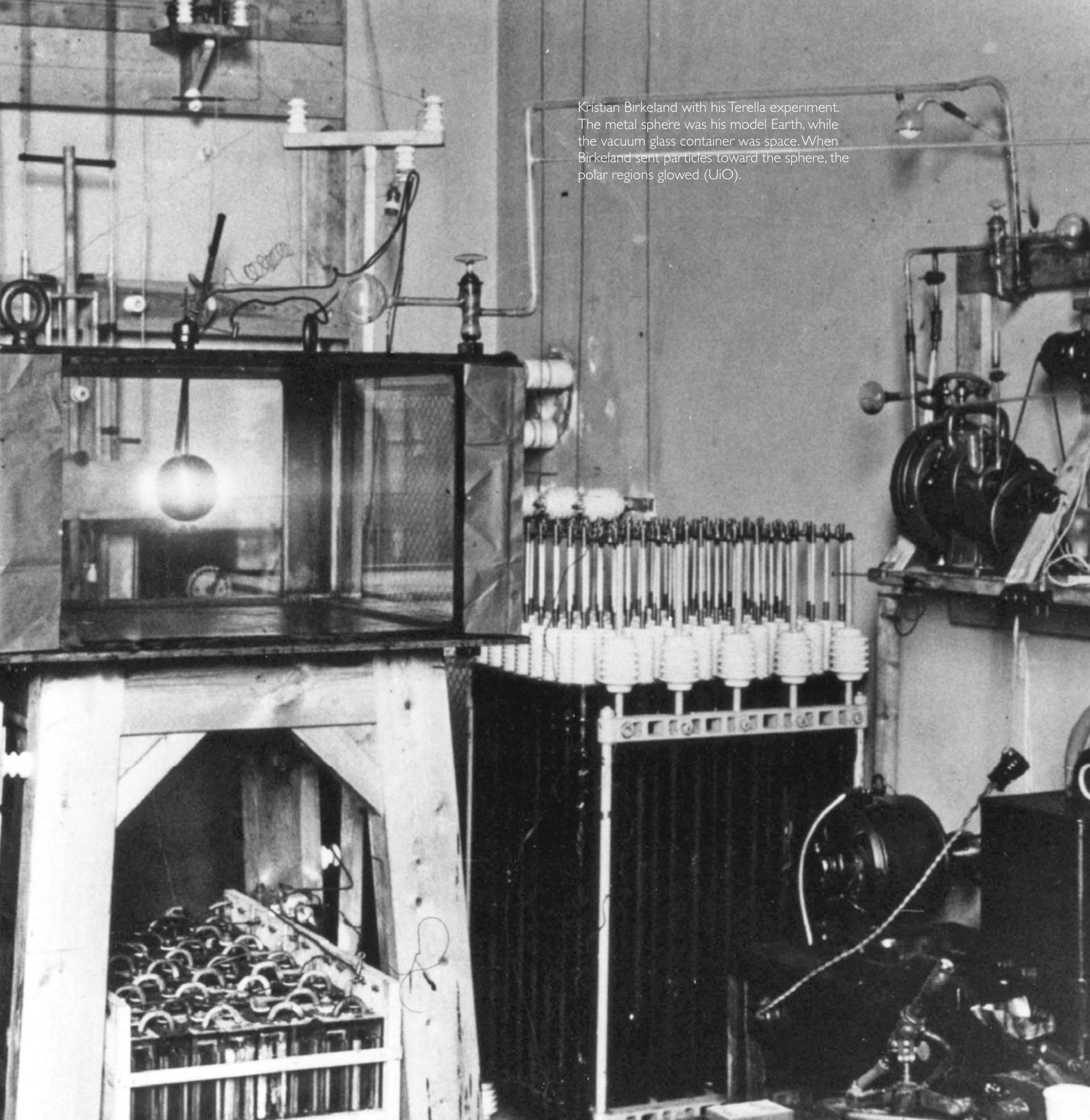
Birkeland has received credit for being the first person to understand the physical connections between the Sun and Earth.



Spectacular northern lights can be seen in the curtain-like structures. The picture was taken in Langhus just south of Oslo on November 8, 2004 (A. Danielsen).

The Norwegian 200 kroner bill shows Birkeland, with his Terella experiment, the Big Dipper, the pole star, and the aurora oval (Norges Bank).

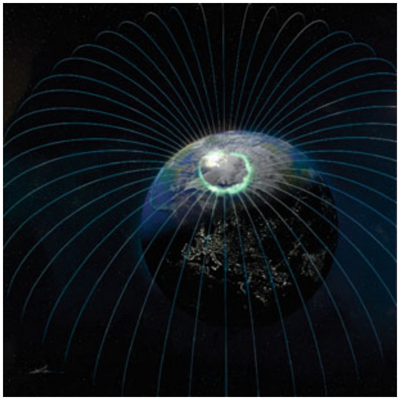




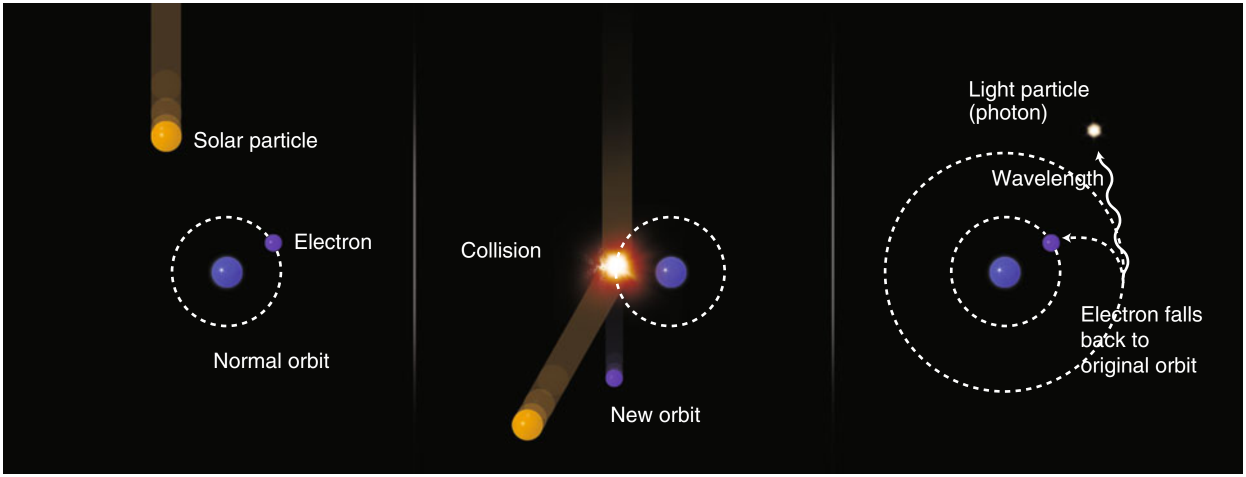
Kristian Birkeland with his Terella experiment. The metal sphere was his model Earth, while the vacuum glass container was space. When Birkeland sent particles toward the sphere, the polar regions glowed (UiO).

How Are the Northern Lights Created?

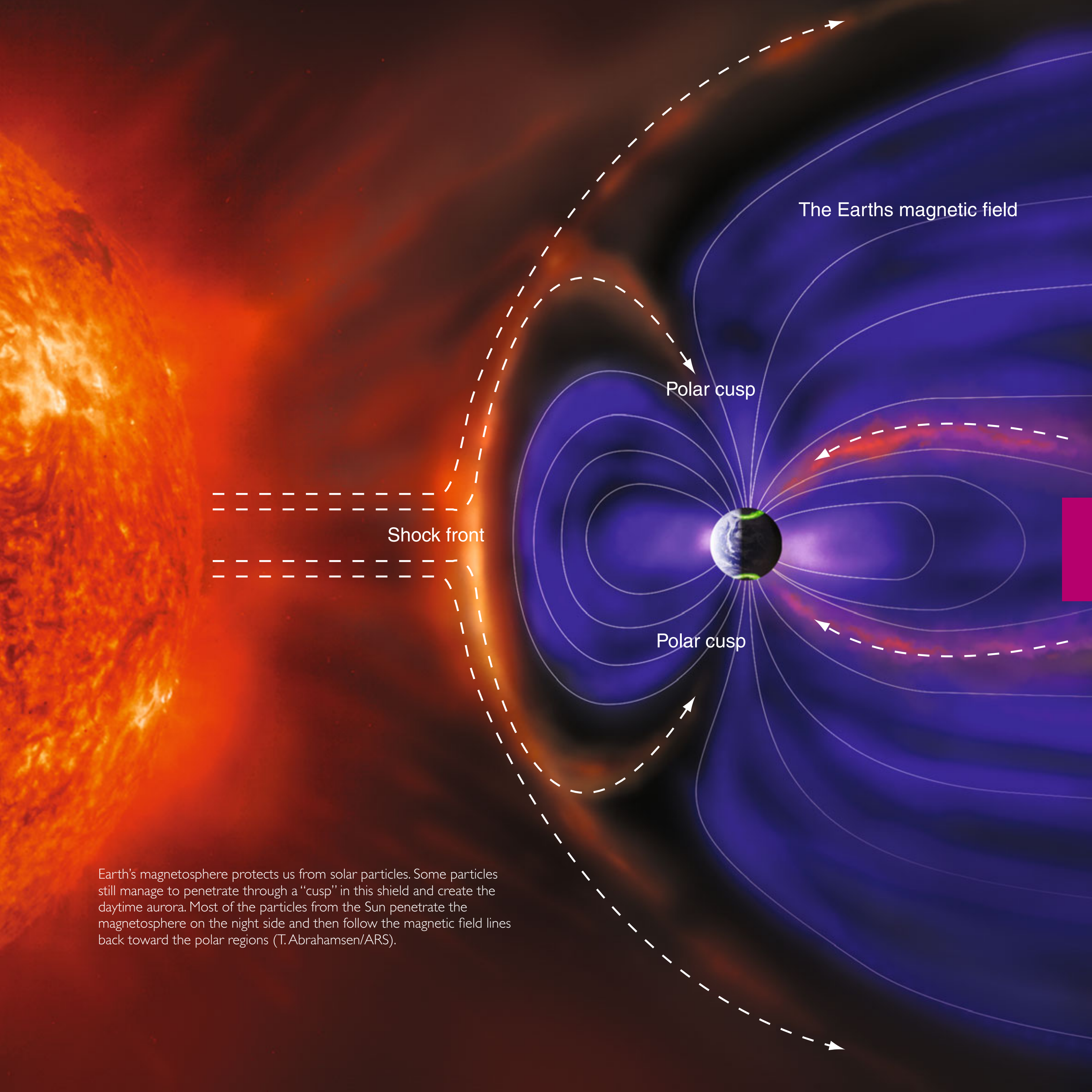
The aurora is formed when particles from the Sun interfere with our magnetosphere. Some particles manage to penetrate the magnetosphere on the night side (tail). When solar storms shake up the magnetosphere, particles inside this magnetic cocoon will be ejected back toward Earth along the magnetic field lines. They are guided down toward the polar regions. When they hit Earth's atmosphere, they collide with oxygen and nitrogen. These collisions, which typically occur at altitudes of between 80 and 300 km, transfer some energy to these atoms (they get excited), which immediately send out light on a certain frequency or color. The result is a spectacular glowing atmosphere with green, red, white, and blue colors. The mechanism is very similar to what happens in a light tube, neon sign, or an old-fashioned TV set. The light is most often seen as far north as Alaska, Northern Canada, and northern Scandinavia, for example. However, after strong solar storms, it can sometimes be seen as far south as Spain and Italy or even Florida. Similarly, the southern lights will mostly be seen very far south.



The northern lights are formed by particles trapped by Earth's magnetic field and channeled down toward the polar regions, where they collide with the atmosphere (T. Abrahamsen/ARS).



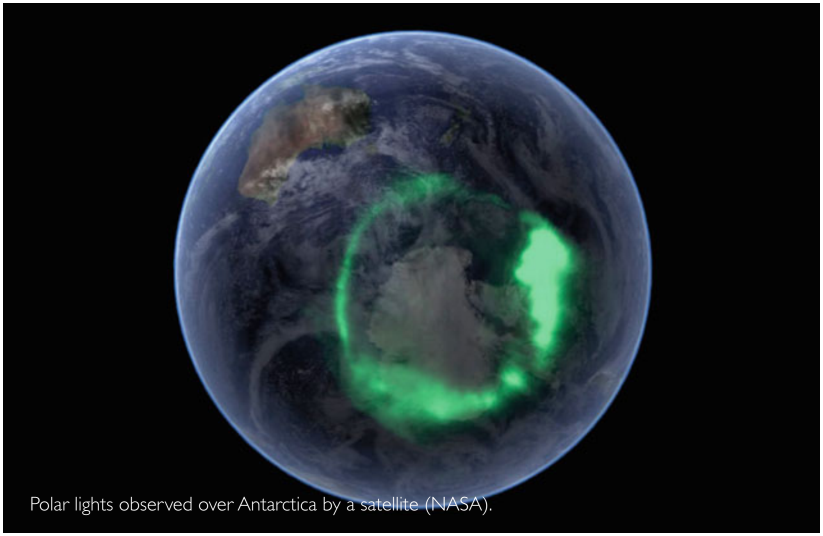
Particles from the Sun collide with atoms in the atmosphere, exciting them so that electrons are lifted up into higher orbits. The electrons will quickly "fall back" to their original orbits and release energy in the form of light (T. Abrahamsen/ARS).



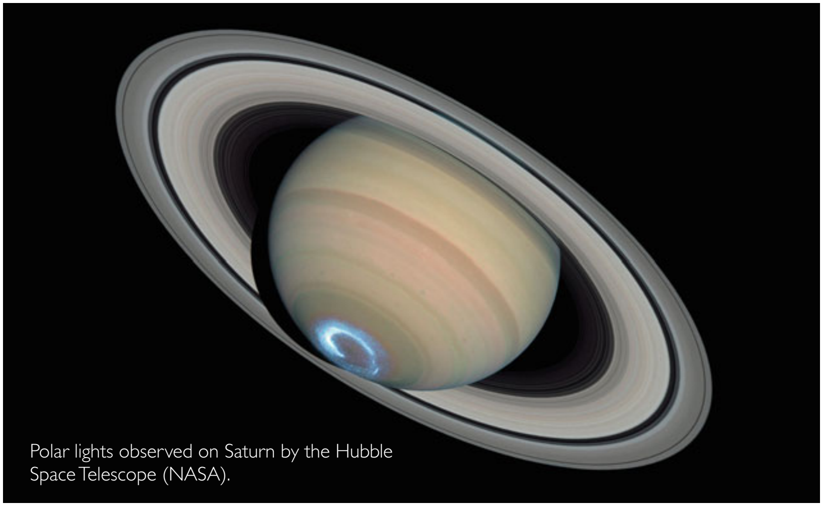
Earth's magnetosphere protects us from solar particles. Some particles still manage to penetrate through a "cusp" in this shield and create the daytime aurora. Most of the particles from the Sun penetrate the magnetosphere on the night side and then follow the magnetic field lines back toward the polar regions (T. Abrahamsen/ARS).

Polar Lights on Other Planets

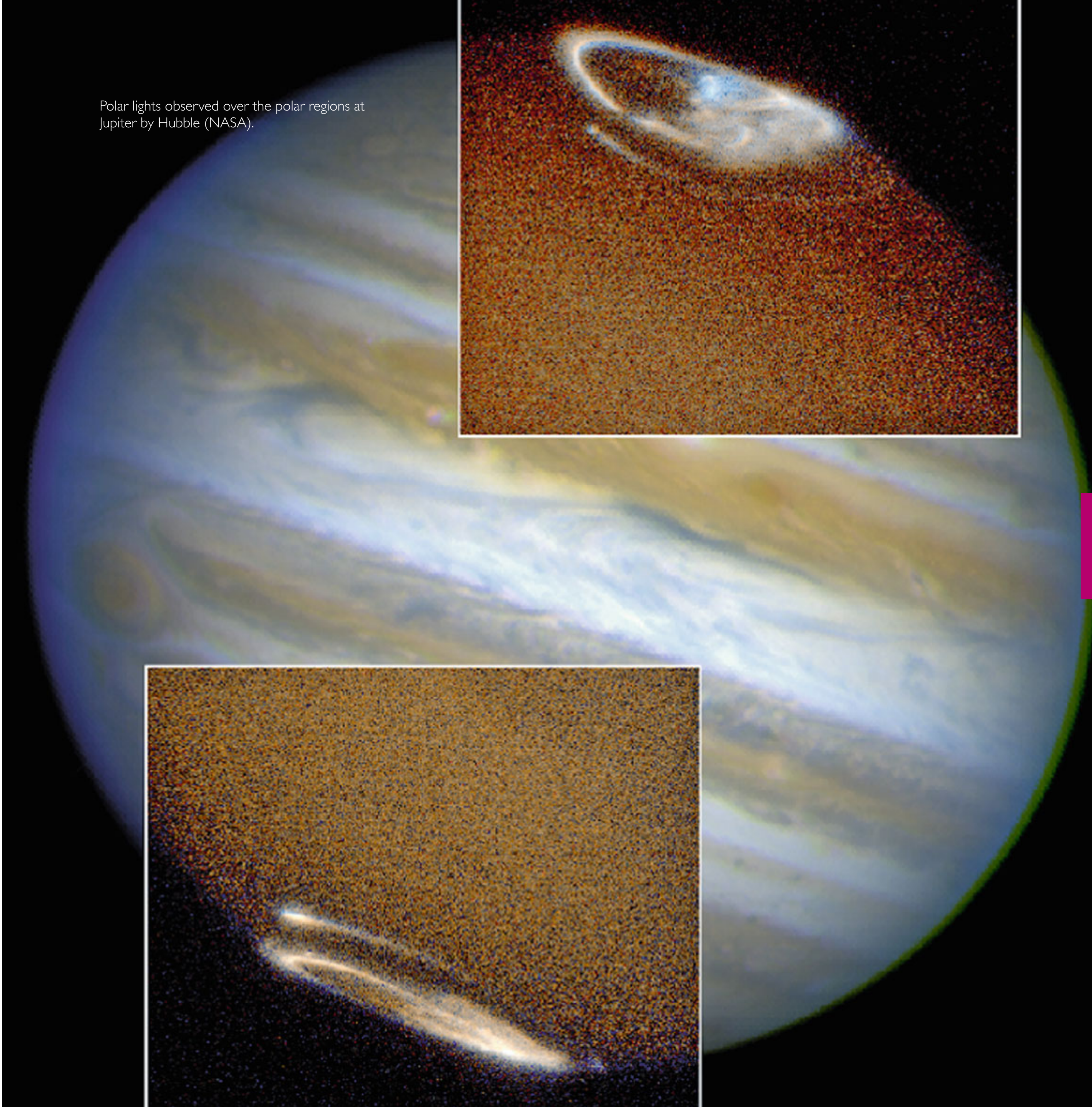
Is it only Earth that experiences polar lights? No. In fact, they can be observed on many other planets such as Jupiter, Saturn, Uranus, and Neptune. These are all gaseous planets with an atmosphere and magnetic fields. The polar lights on these planets are caused by the same mechanism. Large eruptions on the Sun are causing disturbances in their magnetic fields and pumping particles into their atmosphere, which then glow as giant neon tubes. When aurora are observed by satellites, we can see that the polar lights on the planets are very similar to those on Earth.



Polar lights observed over Antarctica by a satellite (NASA).



Polar lights observed on Saturn by the Hubble Space Telescope (NASA).



Polar lights observed over the polar regions at Jupiter by Hubble (NASA).

The Sun can harm humans and electronics in space (NASA).

Space Weather

Did you know that there are storms out in space? And that sometimes these storms can cause damages here on Earth? In addition to creating the beautiful aurora, solar storms have many negative effects. The aurora is a manifestation of something violent happening in our atmosphere, where sometimes 1,500 gigawatts of electricity is generated. This is almost double the energy production in Europe!

Solar storms send out large amount of radiation, particles, gas, and magnetic fields into space, sometimes directly toward Earth. We are lucky that we are shielded from most of the hazardous radiation and particles. This is due to our atmosphere that is preventing UV and X-rays from reaching the ground, and our magnetosphere that is deflecting particles.

The effects from solar storms are called space weather. Did you know that scientists are doing weather forecasting for space?

Satellites are affected by space weather such as "hail storms," when the Sun accelerates high-energy particles that can penetrate and damage the electronics inside. Maybe a "space umbrella" would be useful (T. Abrahamsen/ARS).

How Space Weather Can Harm Our Society

Until about 100 years ago, solar storms could pass by without humans noticing much. However, today, more than 1,000 satellites are operating in space. Our society depends on having these satellites work properly all the time. We use satellites for weather forecasts, communication, navigation, mapping, search and rescue, research, and military surveillance. The loss of a satellite and its signals can have serious consequences.

Solar storms affect important navigation systems and crucial radio communication. Passenger planes flying over the polar regions can lose radio contact with the flight controller. Satellite phones may stop working, and solar storms can knock out some electricity grids.

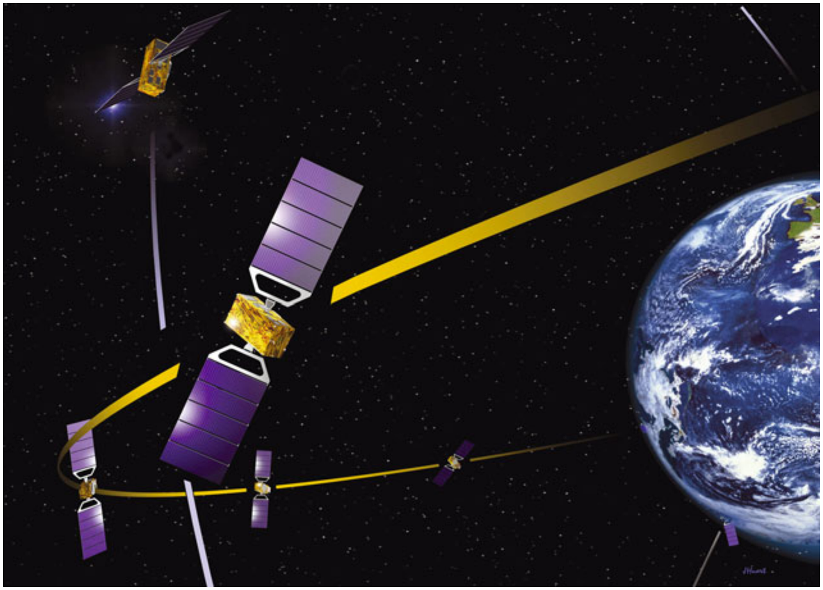
Today, new satellites are monitoring the Sun 24 h every day. They provide space weather forecasts and warn about solar storms that may hit Earth just like the weather forecasts we see on TV every day about the weather.

Did you know that pigeons also are affected by solar storms? They use Earth's magnetic field as one of their navigation systems. After a solar storm, Earth's magnetic field will vary a lot, so that a compass needle will not point correctly. This change can fool the pigeons, too.

During very strong solar storms, we can experience less accurate weather forecasts, lose TV signals, lose electric power, and have navigation systems stop working.

Solar storms can disrupt the power grid when such storms "rattle" Earth's magnetic field and generate large amounts of additional current in the power grid system (P. Brekke).

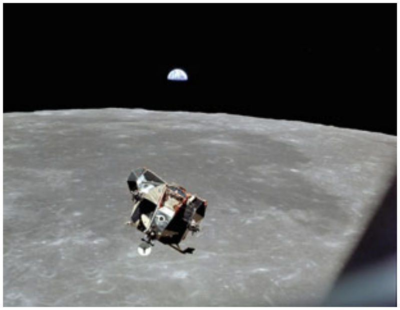
Navigation systems such as GPS and Galileo can be affected by solar storms (ESA).



Solar storms affect our technology-based society in many ways. We are getting more and more vulnerable as our society depends more on space technology (T. Abrahamsen/ARS).

How Space Weather Can Harm People in Space

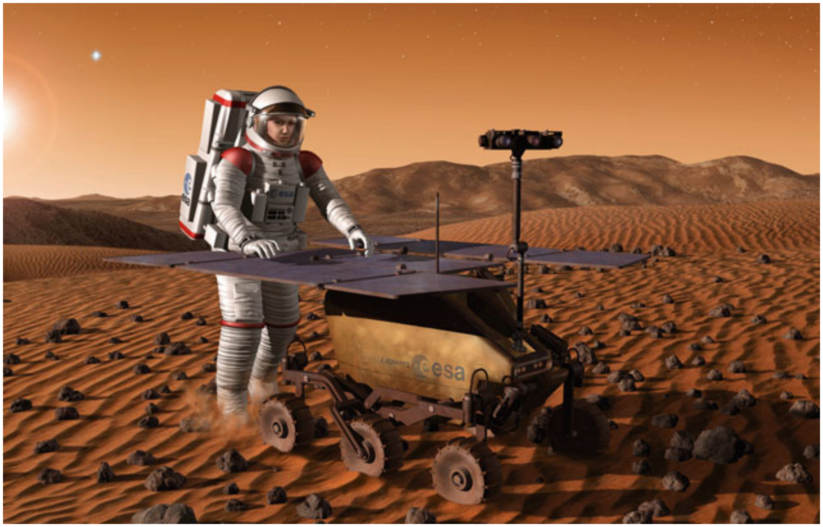
High-energy particles from the Sun can harm humans in space. They penetrate spacecraft and spacesuits and can injure human organs – similar to getting close to radioactive sources. The astronauts on the space station and space shuttle are partly protected by Earth's magnetic fields but can still be exposed to so much radiation during a solar storm that they get sick. The Swedish astronaut Christer Fuglesang was very close to feeling the effects from a solar storm in 2006.



The lunar module "Eagle" on its way toward the command module "Columbia" during *Apollo 11* (NASA).

It is, however, during deep space missions to the Moon or to Mars, outside our protective magnetosphere, that this becomes really dangerous, even inside a spacecraft. It was pure luck that none of the Apollo missions during the 1970s were hit by a strong solar storm. A very strong proton shower occurred in 1972 between *Apollo 16* and *17* that would probably have been lethal had it hit the Apollo capsule.

Such high-energy particles from the Sun are a challenge for future missions to Mars. A round trip will take about 3 years. Thus, we need to find new ways to protect the astronauts by either building spacecraft with new types of material, or even by creating artificial magnetic shields to protect them from solar storms.



Artist's drawing of a future astronaut on Mars. Since the planet does not have magnetic field protection from radiation as we do on Earth, humans on Mars would need good artificial protection from solar storms (ESA).

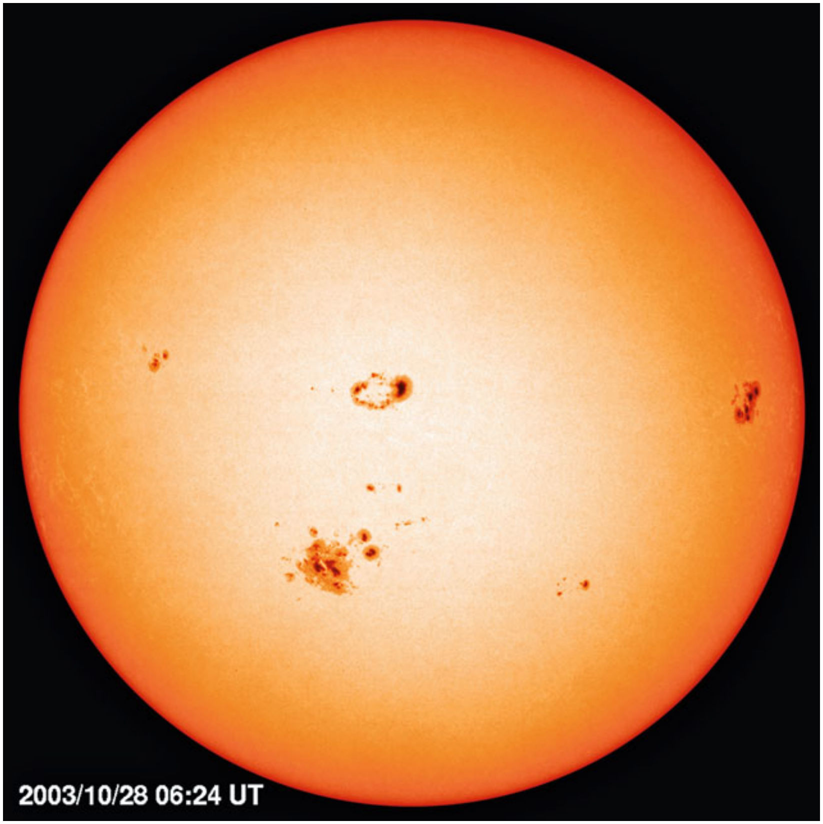
Astronaut Christer Fuglesang floating in space outside the International Space Station (ISS). During one of his space walks, he was exposed to small amounts of radiation (ESA/NASA).

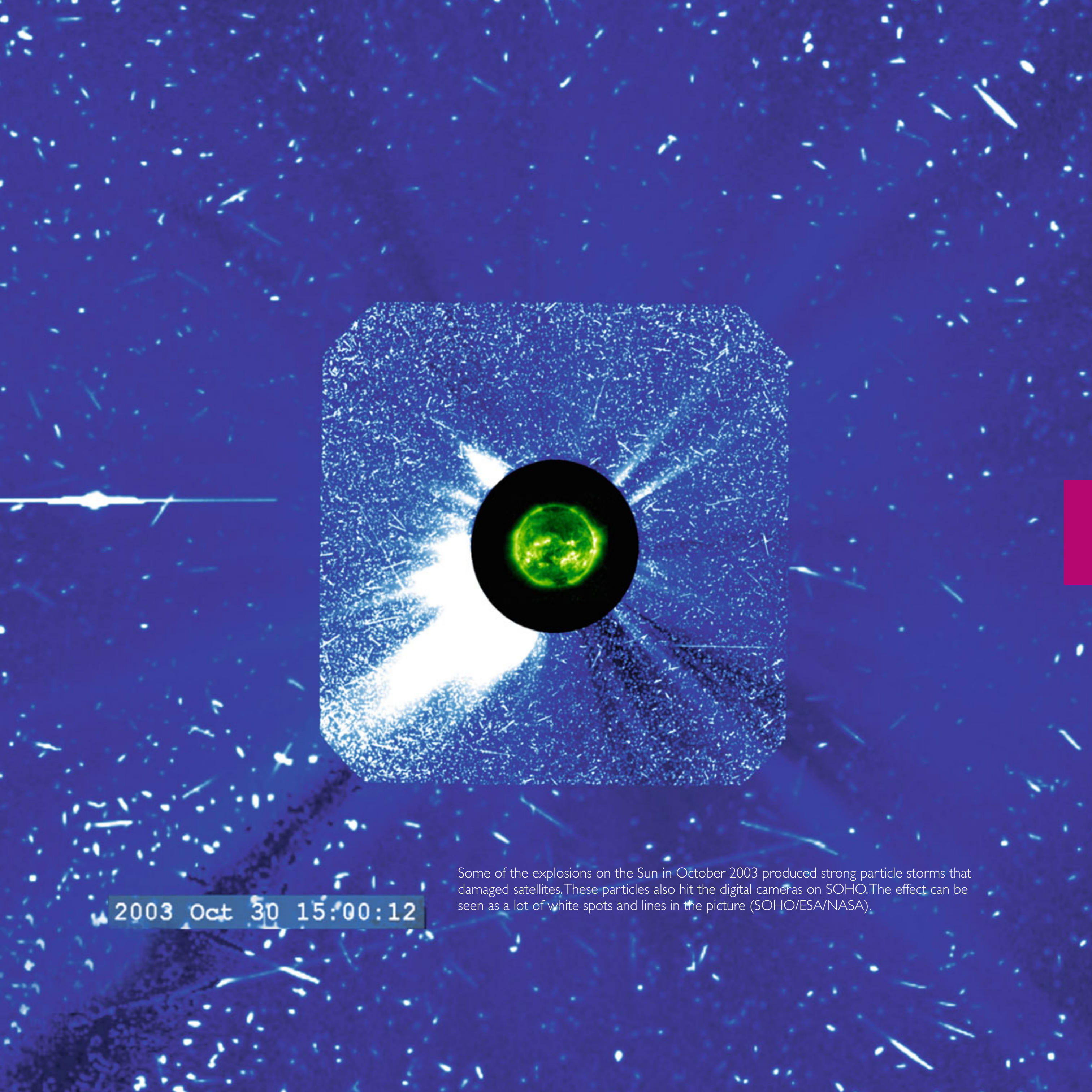
When the Sun Went Berserk

The Sun got the world's attention in the fall of 2003. Three unusually large sunspots were visible, and a record number of solar storms occurred in just 14 days, including the strongest flare in modern times. One of the eruptions reached a record speed of 8.5 million km/h. Several of the eruptions were Earth directed and sparked spectacular auroras visible as far south as Spain and Florida. However, the event also had serious consequences for our technology-based society.

The solar storms generated large amount of high-energy particles that could harm humans in space. Thus, the crew on the ISS was moved to the section with the thickest walls to protect the astronauts. A Japanese satellite was knocked out and many others were affected. Several thousand people lost electricity in southern Sweden, and air traffic control redirected many transatlantic flight further south to avoid problems with radio communication. Even climbers in the Himalayas experienced problems with their satellite phones. These are just some of the problems that were reported after these solar storms.

The Sun observed from SOHO on October 28, 2003. The very large sunspots were visible with the naked eye when the Sun was low on the horizon (SOHO/ESA/NASA).





Some of the explosions on the Sun in October 2003 produced strong particle storms that damaged satellites. These particles also hit the digital cameras on SOHO. The effect can be seen as a lot of white spots and lines in the picture (SOHO/ESA/NASA).

Solar Activity and Climate Change

Earth has experienced large climate shifts in the past. Even during the last few thousand years, there have been large temperature variations. One thousand years ago, it was warmer on Greenland than today. Vikings settled down on the grassy hills and grew crops. This was during a period when the Sun was very active and somewhat brighter. Later, as the Sun became more quiet and the temperature fell, the ice moved closer to the ocean and the fjord froze. The people had to abandon Greenland.

The last 100 years of human activity has also contributed to climate change due to land use changes, deforestation, and the emission of greenhouse gases. Today there is increasing concern about future climate change due to human activity. Human-driven climate change will work in addition to natural climate variability mainly caused by the Sun.

If we want to understand human-caused climate change, we also need better knowledge about natural climate variability. If we learn more about the Sun, we may be able to predict how it will vary in the future.

We know that variations in solar activity contribute to climate change. In particular, when we go far back in history, we find strong evidence that the Sun was an important driver for the climate. Thus, better knowledge about how the Sun varies is important (Instituto de Astrofisica de Canarias).

There is an increasing concern about the climate effects from emission of greenhouse gases (dreamstime.com).

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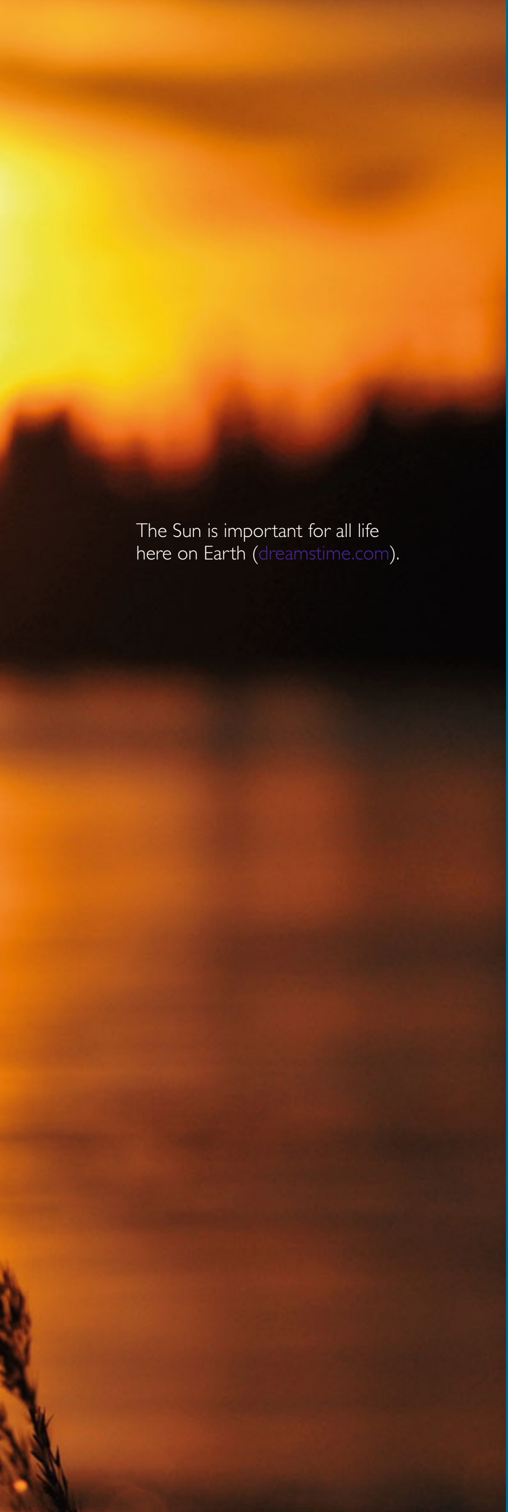


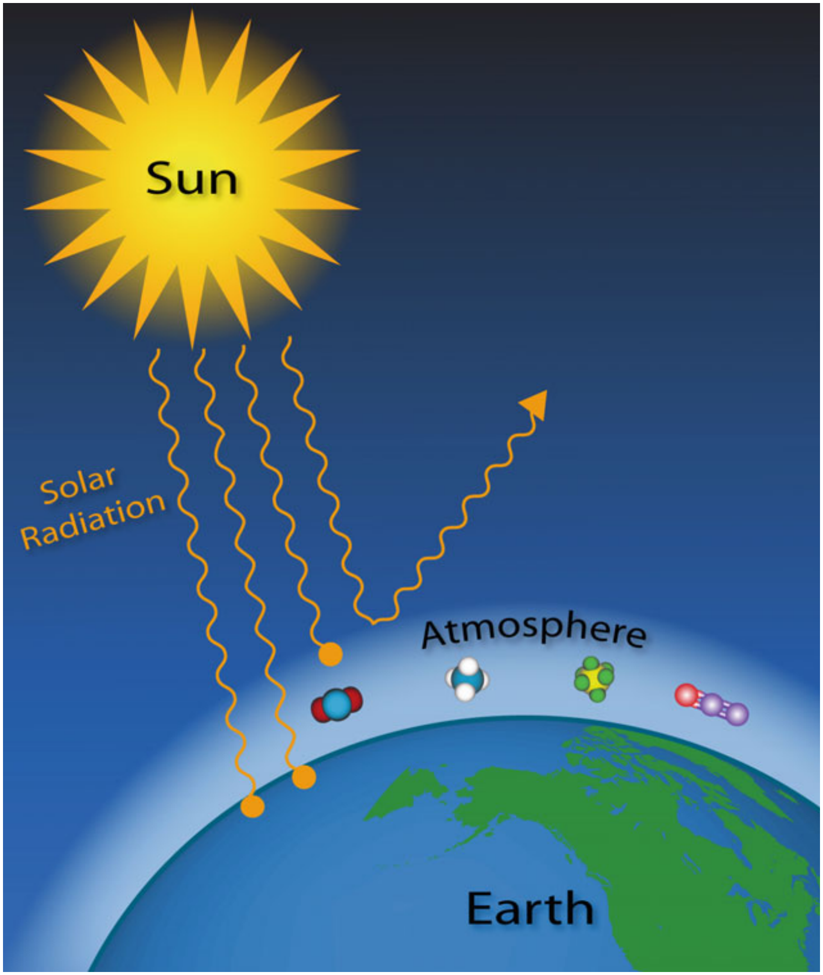
The Sun is important for all life here on Earth (dreamstime.com).

THE SUN AND LIFE ON EARTH

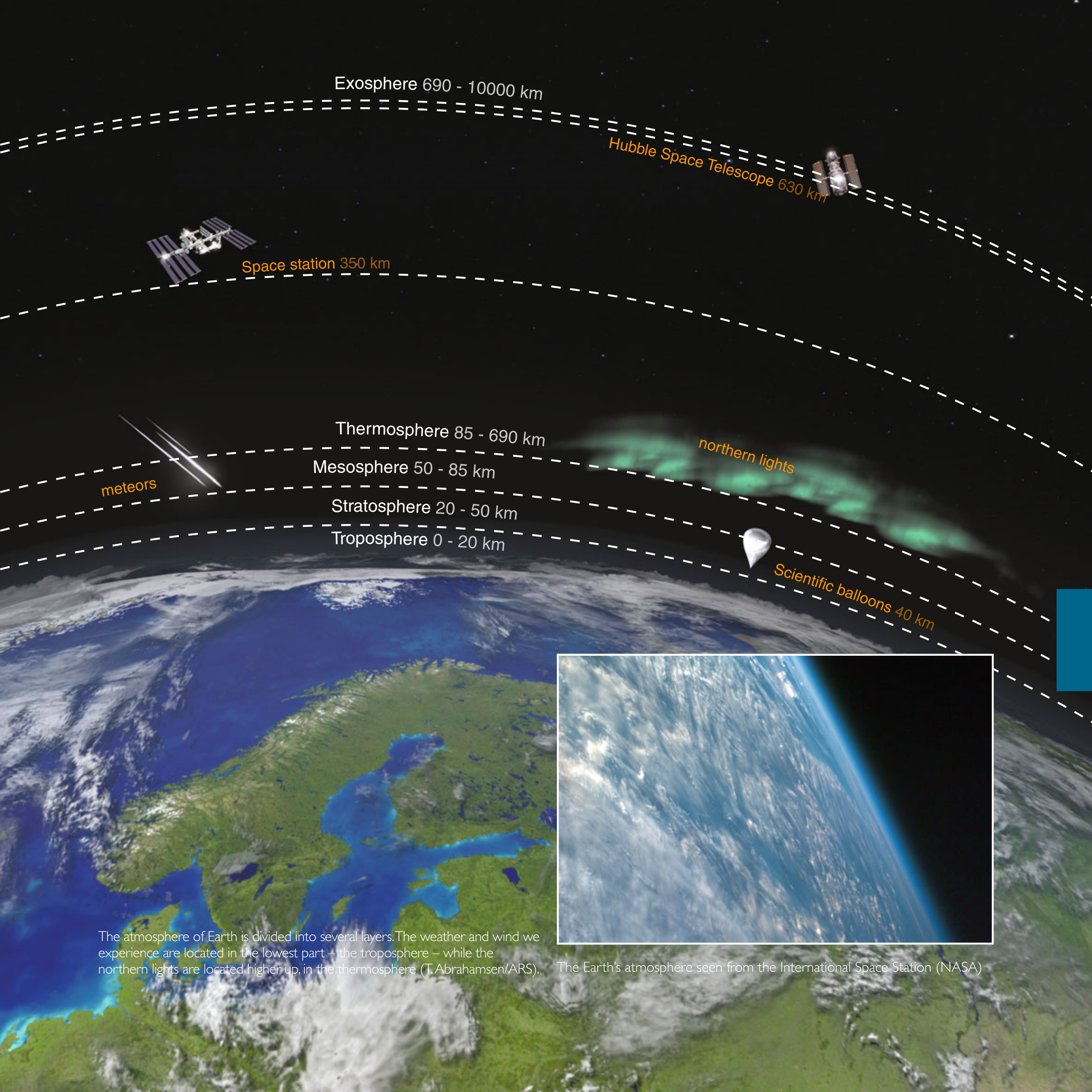
Earth's Atmosphere

It is Earth's atmosphere that makes it possible for life to exist. This prevents dangerous radiation from the Sun from reaching the surface. At the same time, it is so "smart" that it allows solar energy to penetrate, but prevents the heat from escaping out in space again. Thus, it works as a blanket that keeps us comfortably warm day and night. This effect is called the greenhouse effect.

It is the gravity of Earth that "holds" the atmosphere in place and prevents the gases from evaporating into space. The atmosphere contains the air that we breathe, and also a type of oxygen we call ozone. This gas is mostly known for protecting us from the hazardous ultraviolet radiation from the Sun. Strangely it is this radiation that is producing the vital ozone layer. The atmosphere is thickest close to the ground and gets thinner and thinner higher up.



Gas and particles in the atmosphere contribute to the natural greenhouse effect. The atmosphere allows visible light from the Sun to penetrate down to the ground but traps the reflected outgoing infrared light. This is the mechanism that maintains a comfortable average temperature here on Earth (NASA).



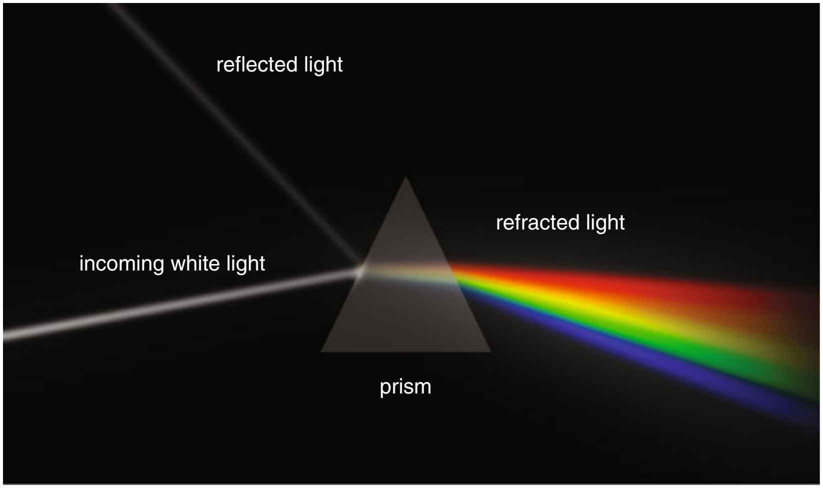
The atmosphere of Earth is divided into several layers. The weather and wind we experience are located in the lowest part – the troposphere – while the northern lights are located higher up, in the thermosphere (T. Abrahamsen/ARS).

The Earth's atmosphere seen from the International Space Station (NASA)

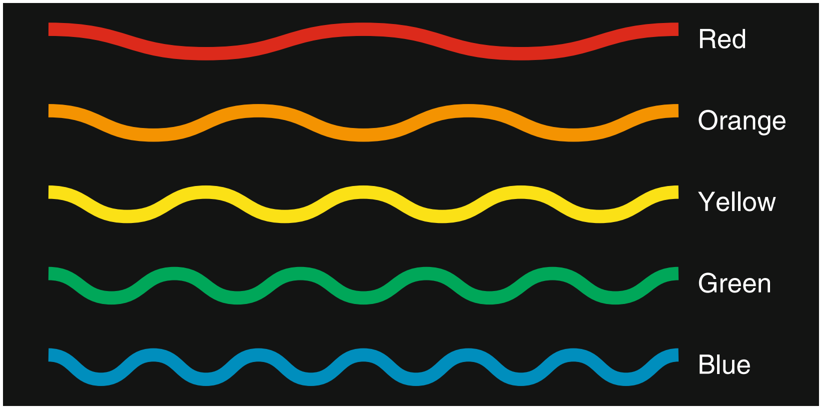
Sunlight and Blue Sky

Why is the sky blue here on Earth? The light from the Sun, and from ordinary light bulbs, appears white. Even if the light appears white, it contains all the basic colors: red, orange, yellow, green, blue, indigo, and violet. When we send white light through a prism of glass, it emerges on the other side separated into the individual colors.

The energy of light is transported by waves, almost like waves on the ocean. Some colors move with short "choppy" waves; other move with long waves (ocean swells). Blue light has shorter waves than red light. And light moves in straight lines unless it is reflected by a mirror, refracted, or bent by a prism or a raindrop, or scattered by molecules in the atmosphere. The blue sunlight, with the short waves, is scattered more than all the other colors by the molecules in the air. Thus, the sky appears mostly blue, while the light from the Sun looks whitish-yellow.



White light passing through a prism will be dispersed into the individual colors of the optical spectrum. The same happens when light passes through tiny raindrops and creates a rainbow (T. Abrahamsen/ARS).



The individual colors are bent differently, depending on their wavelength or frequency. Blue light has shorter, choppier waves, while the red light has longer waves. Just like waves on the ocean, light waves have different distances between their wave tops (T. Abrahamsen/ARS).

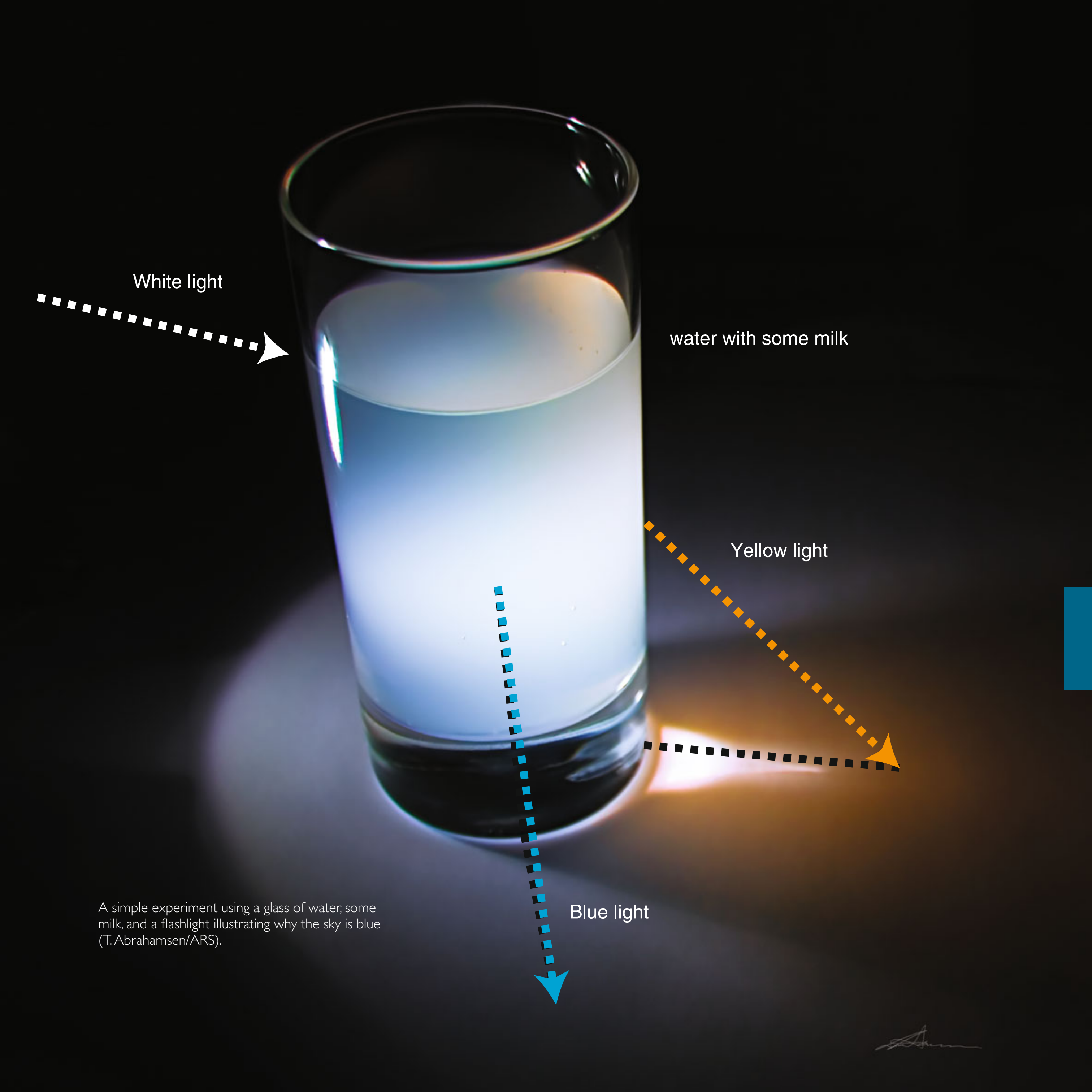
The blue light is scattered more than other colors by the molecules in the atmosphere. Thus, we see blue light reflected from the entire sky and it appears blue. Some of the blue light has therefore been "stolen" by the atmosphere, so the Sun appears yellowish (T. Abrahamsen/ARS).

Explaining the Blue Sky: A Simple Experiment

Scattering of light in the atmosphere can easily be demonstrated with a flashlight, a glass of water, and some milk. In a dark room, look at the flashlight through the water or place a piece of white paper close to the glass. You will see a white light. Add a few drops of milk to the water and stir. What happens with the color of the water and the "sun" (light bulb)? Add some more milk and see what happens.

A blue sky over the island Lyngør with fog creeping in from the ocean (P. Brekke)

Earth's atmosphere and a crescent Moon observed from the ISS. Note that the lower part of the atmosphere is orange while the upper part is blue (NASA).



A simple experiment using a glass of water, some milk, and a flashlight illustrating why the sky is blue (T. Abrahamsen/ARS).

The Red Sunset

When the Sun is low on the horizon, the light has to pass through much more atmosphere than when the Sun is high in the sky. Then, even more blue light is scattered and "removed" from the sunlight, making it appear orange and even red. Sometimes the sky also turns red. This is caused by larger particles such as dust, pollution, and water vapor that reflect and scatter some of the red and yellow color.

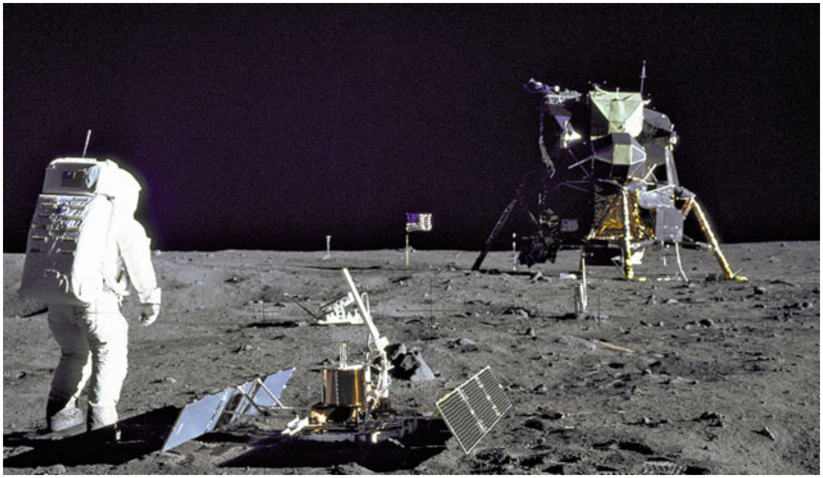
Those locations on Earth with the most air pollution often experience the reddest sunsets. Large volcanic eruptions eject large amounts of ash into the atmosphere and can also cause very red sunsets over large areas. Even a volcano on Hawaii could produce extra red sunsets in large parts of the United States.

A red sunset over the Oslo fjord with the tallship Christian Radich (P. Brekke).

When the Sun is low on the horizon, the light has to pass through more atmosphere. Therefore, even more blue light is scattered ("stolen") from the white sunlight and the Sun appears red. Larger particles in the air will also scatter red light, producing a reddish sky (T. Abrahamsen/ARS).

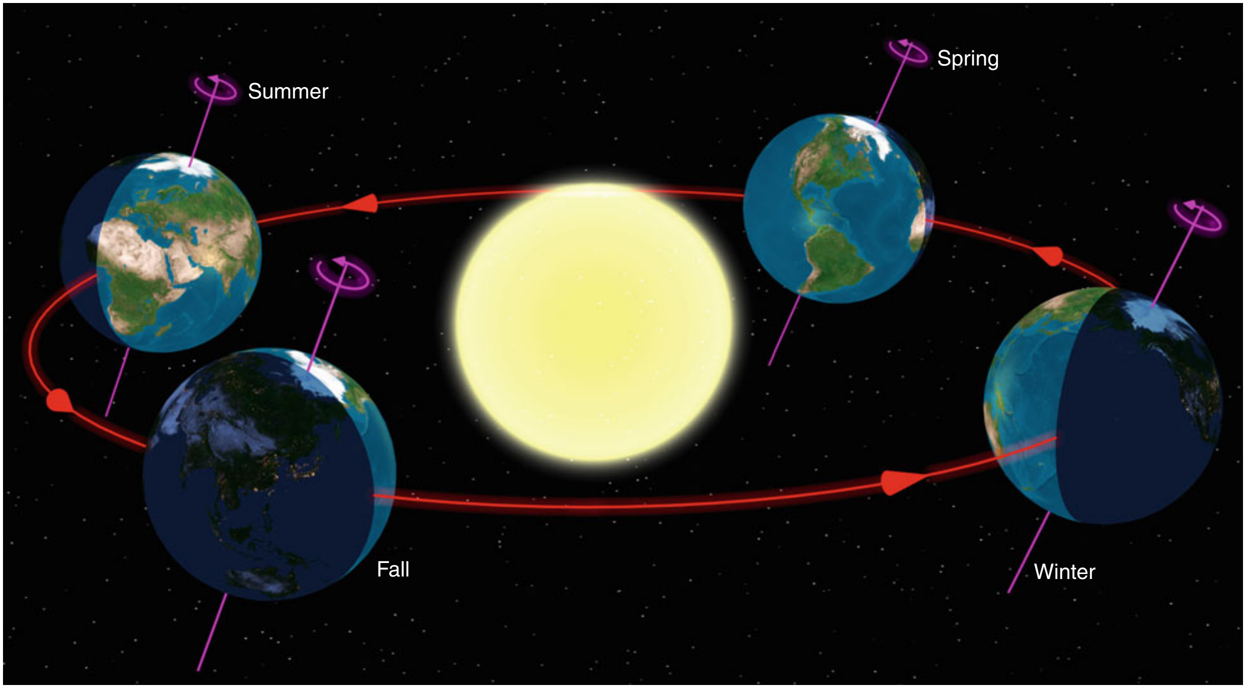
Black Sky on the Moon

What would the sky look like if Earth did not have an atmosphere? The sky would look black and you would not see any red sunset. However, you would be able to see stars in the middle of the day. Here on Earth, the light from the stars is overwhelmed by all the scattered blue light from the atmosphere. The reason we do not see stars in the pictures taken during the Apollo missions to the Moon is that the exposure times were adjusted to capture details on the very bright lunar surface.



The astronauts on the Moon placed several scientific instruments on the lunar surface during the Apollo missions. The sky is always pitch dark there since there is no atmosphere (NASA).

When the Apollo capsule was orbiting the Moon, the astronauts could see Earth rise over the lunar horizon (NASA).



Earth's axis of rotation is tilted and points toward the Sun during summer, resulting in long and warm summer days at high latitudes in the northern hemisphere (Wikipedia).

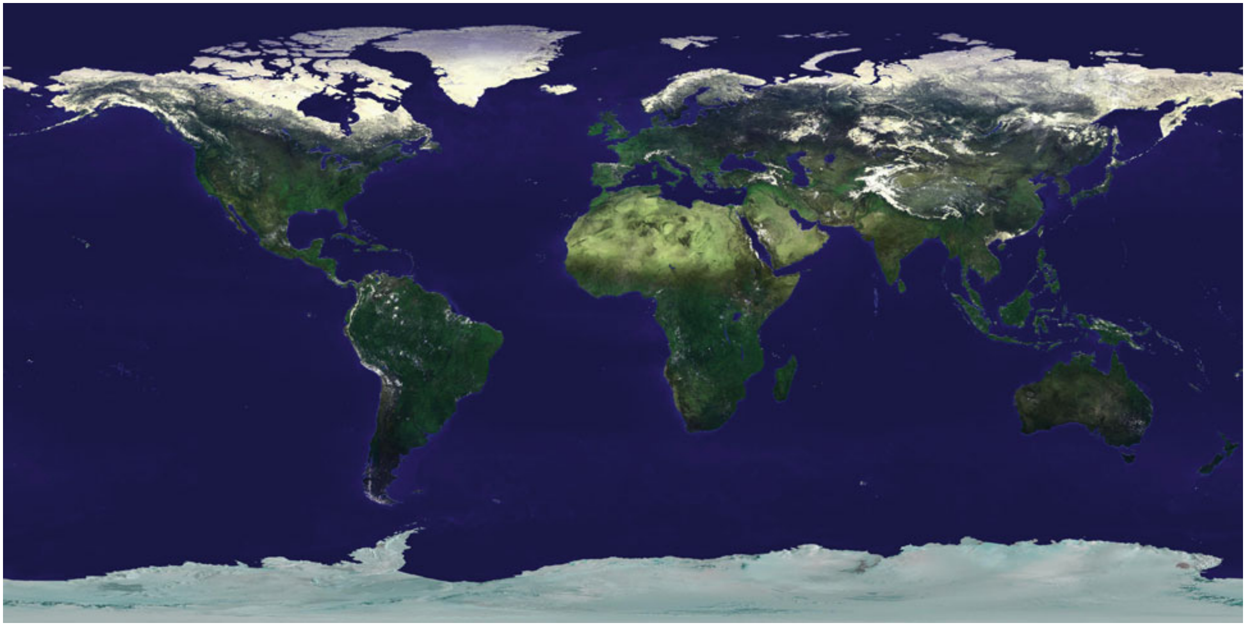
The Seasons

Why is it warmer in the summer in the Northern Hemisphere when Earth is actually farthest away from the Sun? Earth does not revolve around the Sun in a circular orbit but in an elongated elliptical orbit. At winter solstice the distance to the Sun from Earth is 147.5 million km. At summer solstice, it is 152.6 million km. In other words, the Earth is 5 million km farther away in the summer. This means Earth receives 7% less energy from the Sun in the summer. So, why is it still warmer here in the north?

It all has to do with the tilt of Earth. Earth is tilted from perpendicular to the plane of the ecliptic by 23.5°. In the north, the Sun's rays hit Earth at a more direct angle in the summer and the Sun is high on the sky. In the Southern Hemisphere, the Sun is then low on the sky and people there experience winter. However, is this the complete answer?

An artistic way of illustrating that Earth has four seasons (M. Rotzinger).

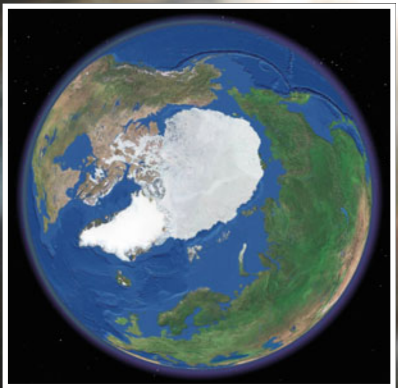
Since Earth's rotational axis is tilted, we experience seasons. Here are some pictures from Lyngør in summer and winter (P. Brekke).



Earth as seen from space, assembled from many satellite images. It shows the distribution of land and oceans (NASA).

The Seasons and Temperature

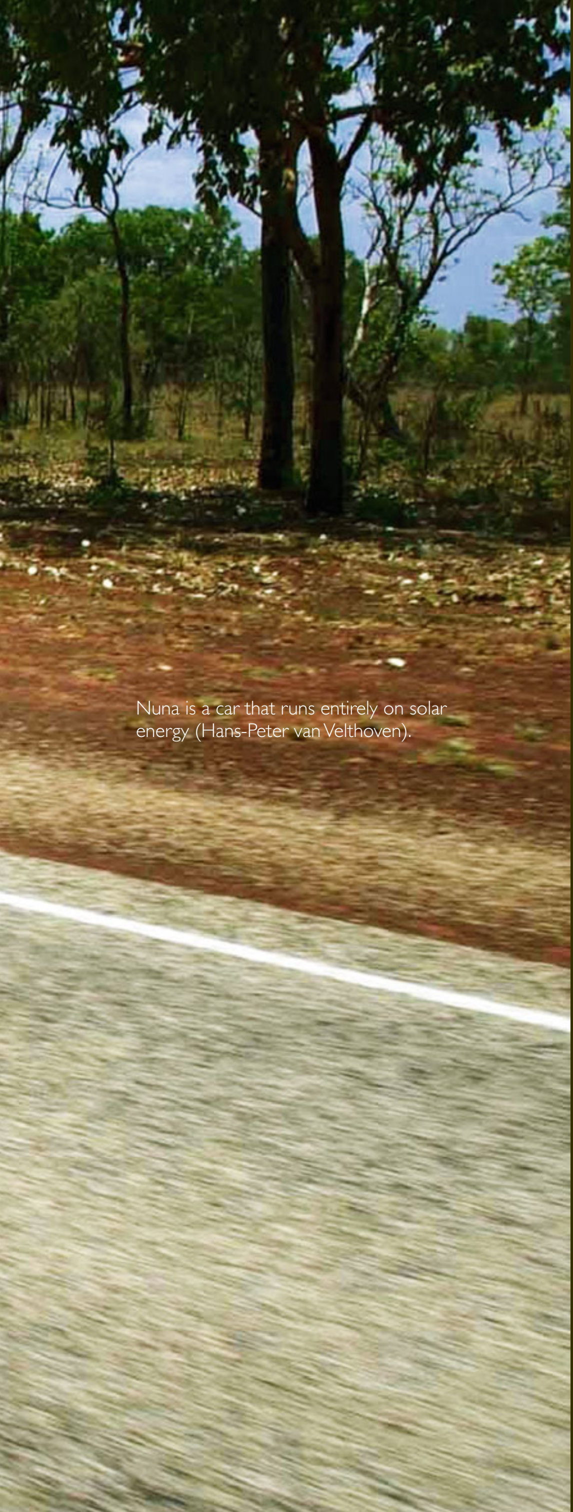
Interestingly, the average global temperature is 2.3°C higher when Earth is farthest from the Sun – in the summer. This is kind of strange, since one would expect the average temperature to be about the same since the Southern Hemisphere would experience corresponding summer temperatures when we have winters in the north. The reason is that the landmasses and the oceans are not distributed evenly around Earth. There are more landmasses in the Northern Hemisphere, and more ocean areas in the Southern Hemisphere. Since landmasses heat up faster than oceans, the Northern Hemisphere will have a higher average temperature.



The two hemispheres of Earth where one can clearly see that there are more oceans covering the Southern Hemisphere (NASA)

We can measure variations in temperature between day and night and between summer and winter. The reason is Earth's rotation and its orbit around the Sun (P. Brekke).

Pål Brekke, *Our Explosive Sun*,
DOI 10.1007/978-1-4614-0571-9_8,



Nuna is a car that runs entirely on solar energy (Hans-Peter van Velthoven).

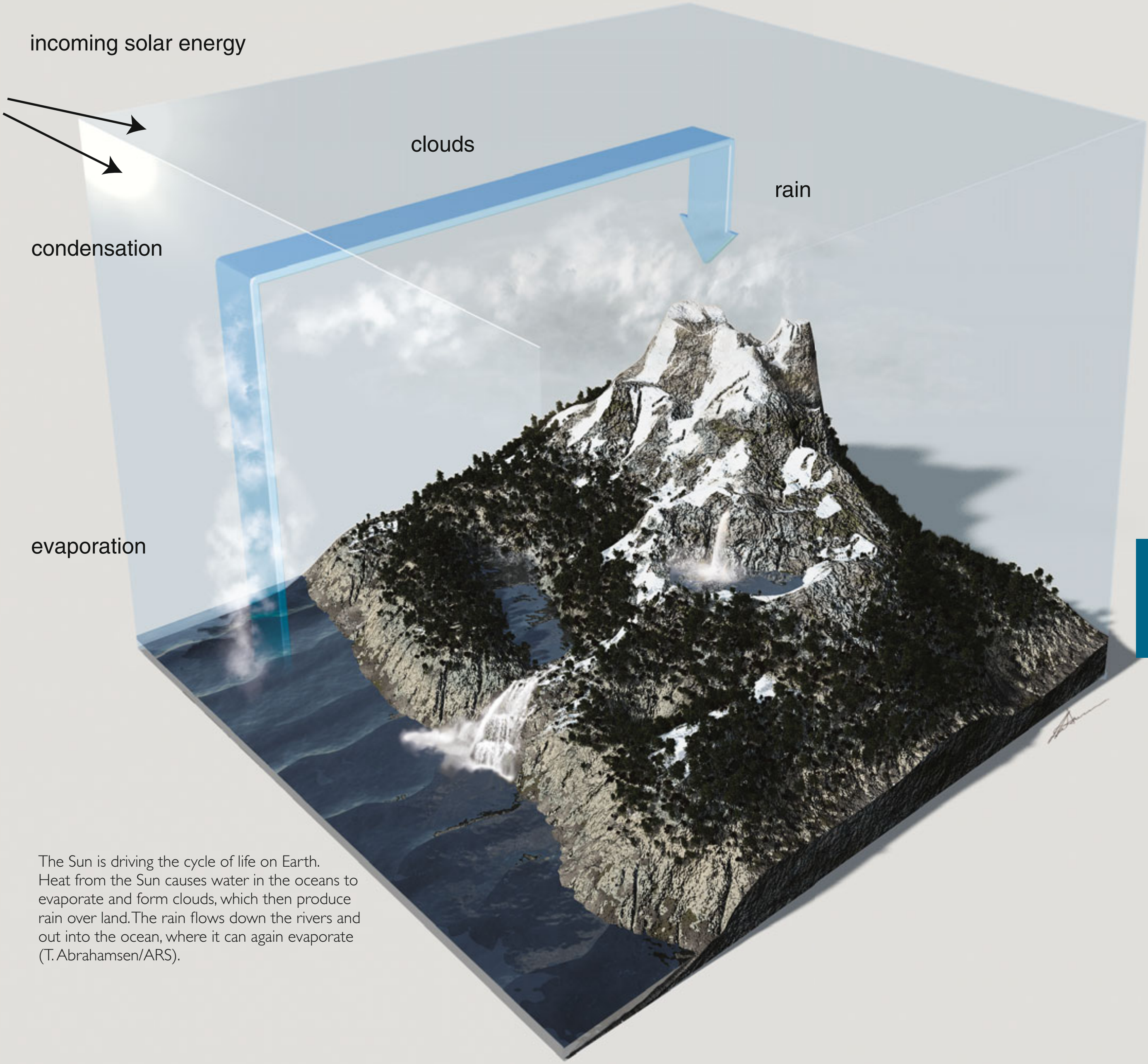
HOW WE UTILIZE THE SUN

How Humans Depend on the Sun

The Sun heats up our landmasses, oceans, and the air. It gets water to evaporate to create clouds. When the water vapor is cooled, small water droplets are formed inside the clouds, and these will fall down as rain and provide water to plants, animals, and humans. The plants are using sunlight to convert carbon dioxide (CO_2) and water to carbohydrates. At the same time, they release oxygen that humans need to breathe. This process occurring in plants is called photosynthesis, and the plants need the carbohydrates to grow, just like humans and animals. Thus, the Sun drives the entire circle of life. Did you know that ultraviolet rays from the Sun are producing the important D vitamins our bodies need?

Plants need sunlight to grow and produce oxygen through a process called photosynthesis (P. Brekke).

Humans need sunlight for our bodies to produce some vitamins (P. Brekke).



The Sun is driving the cycle of life on Earth. Heat from the Sun causes water in the oceans to evaporate and form clouds, which then produce rain over land. The rain flows down the rivers and out into the ocean, where it can again evaporate (T. Abrahamsen/ARS).

The heat from a fire is in fact old stored solar energy (K. A. Aarmo).

The Sun: Our Source of Energy

Have you ever thought about where the heat from a fireplace comes from? Or where the energy from hydropower comes from? Or where the energy we get from oil and gas comes from?

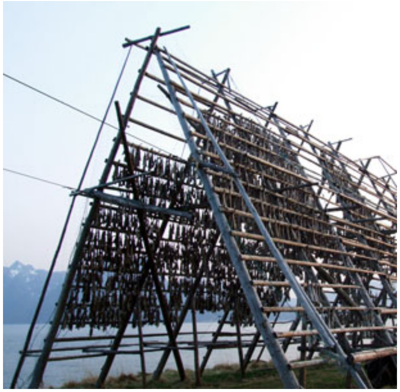
The heat and energy, all stem originally from the Sun. These are all forms of "stored" solar energy. Sunlight allows the tree to grow, and we get some of this energy back when we burn wood. After many thousands of years, a dead tree will be converted to oil and coal. This energy we can exploit today for electricity, fuel, and heat. The heat from the Sun makes some water evaporate from the oceans, creating clouds that can drop the water over land. The water will flow down the rivers, where we can extract energy from hydroelectric power plants. Thus, the Sun is the main source of the energy we are using in our daily life.

When we extract oil and gas from the bottom of the oceans, we are collecting solar energy that has been stored for millions of years (Statoil).

Many people are still using the Sun to dry clothes (D. Warren).

How We Use Solar Energy

For thousands of years, humans have used solar energy to dry food and clothes. Only more recently have we discovered techniques to convert this energy into electricity. The total effect of the Sun is an amazing 386 billion billion megawatts. Even if only a very small part of this energy hits Earth, it would be enough to provide our total energy demand worldwide – if we could only manage to exploit it more effectively. In fact, every year Earth receives 15,000 times more energy than the world consumes today.

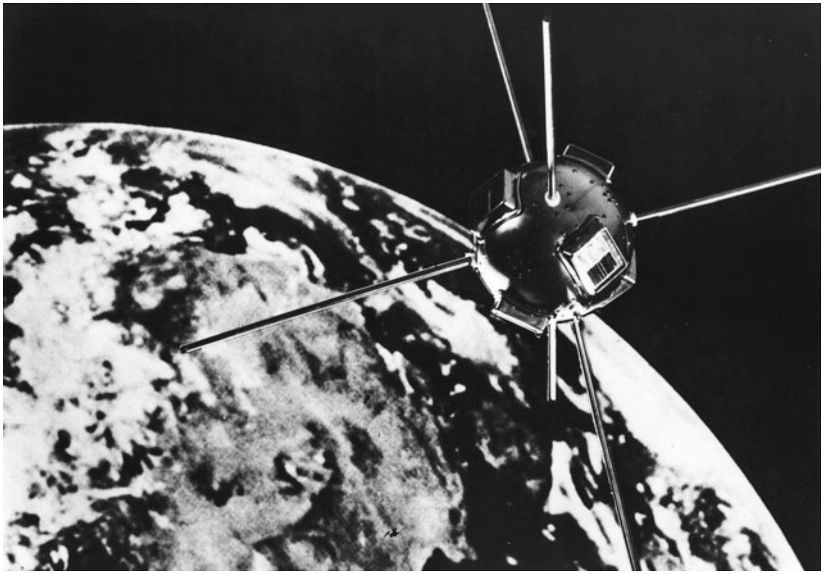


For ages, humans have utilized solar energy, for example, to dry fish (R. Bertinussen).

Solar energy will be an important part of future energy sources. However, we will never see 150-million-km-long power lines from the Sun (A. I. Berget).

Solar Cells

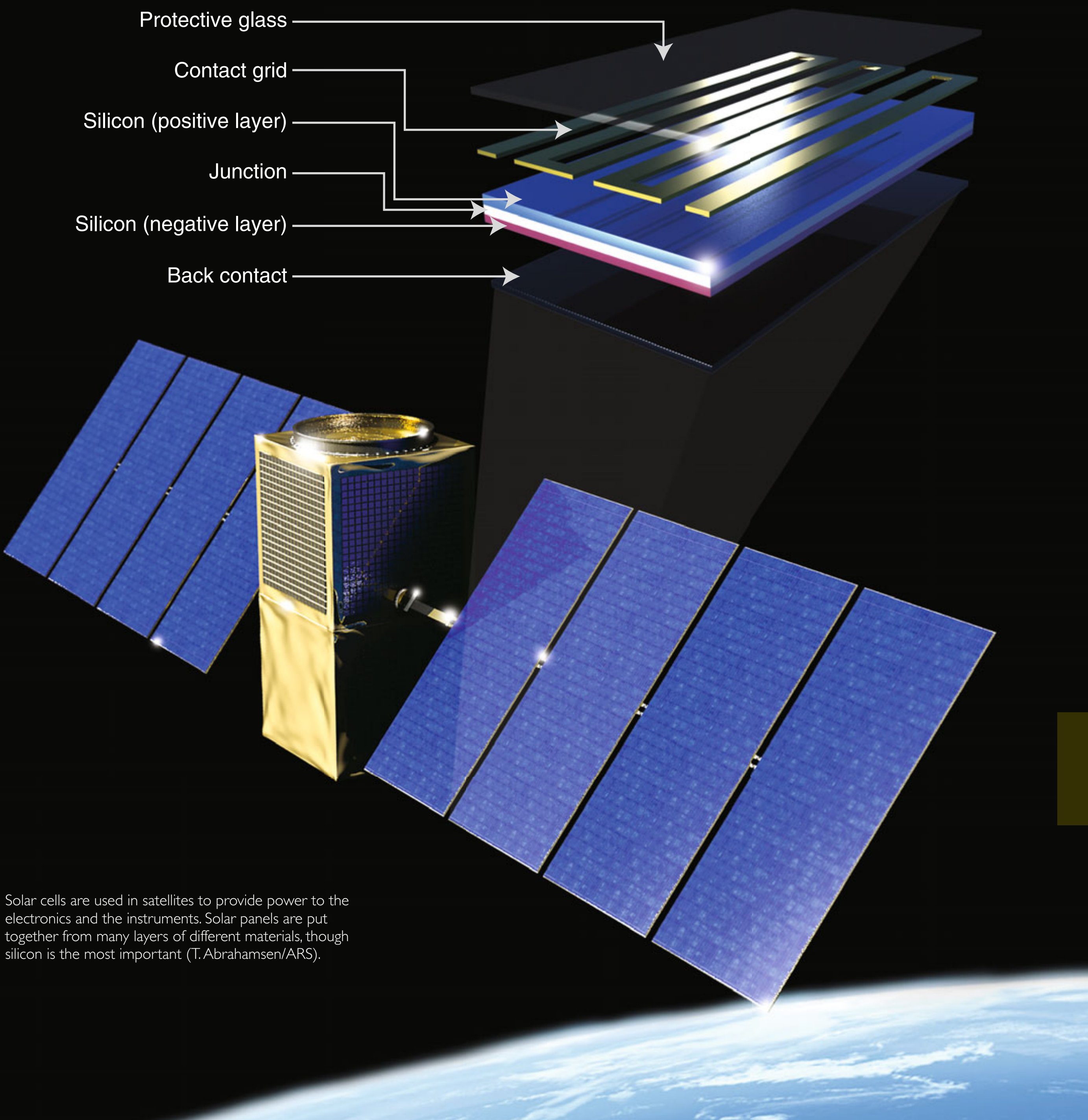
Edmund Becquerel, a 19-year-old French physicist, discovered in 1839 that some materials could produce a weak current when illuminated with light (Edmund is the father of Henri Becquerel, who discovered radioactivity). We had to wait 100 years before this technique was ready to be used in practice. The need to find ways of powering satellites in space motivated engineers to develop solar cells. The first satellite powered by solar cells was the *Vanguard,* launched on March 17, 1958.



Vanguard I was the first satellite powered with solar cells. This grapefruit-sized satellite was launched on March 17, 1958 (NASA).

Solar cells (often made out of silicon) convert light directly to electricity when light photons kick loose electrons in the silicon. These free electrons can then move and create a current. Electricity from solar cells is a renewable source of energy and does not pollute. As long as the Sun shines on the solar cell, there will be electricity.

Solar cells are usually made out of silicon, which transforms light into electric current (REC/D. Heinisch).



Solar cells are used in satellites to provide power to the electronics and the instruments. Solar panels are put together from many layers of different materials, though silicon is the most important (T. Abrahamsen/ARS).

Uses of Solar Cells

Today all satellites orbiting Earth are using solar cells. The astronauts on the ISS get electricity from giant solar panels. NASA has even developed an airplane powered completely by solar energy. Solar cells are also used more and more on the ground and are smart solutions where "transport" of electricity is difficult. You may have seen traffic lights or small lighthouses with solar panels. You can buy a calculator that runs on solar cells, and there are solar cell–driven chargers for cell phones. Solar cells can be built soft and thin, and it is in fact possible to make a jacket that would charge up your MP3 player.

So why do we not use more solar energy rather than electricity made from coal and oil? The reason is mainly that it still costs more to produce solar energy compared to oil and coal. However, new technologies will hopefully change this in the future. Large power plants based on solar energy have already been built.

The Hubble Space Telescope receives power from solar cells (NASA).

This solar power plant in Spain is using a large number of mirrors reflecting sunlight toward the top of the tall tower. The intense focused light heats up water, and the steam it produces is driving a turbine and generating enough energy for 6,000 homes (flickr/afloresm).

NASA has built an airplane running on solar power (NASA).

Many lighthouses along the coastline of Norway obtain electricity from solar panels (P. Brekke).

Pål Brekke, *Our Explosive Sun*,
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Using specially designed eclipse glasses you can view the Sun safely. If there are large sunspots, you may see them with such glasses (P. Brekke).

HOW YOU CAN STUDY THE SUN AND THE AURORA

How to Observe Sunspots

It can be fun to study the Sun and see how the number of sunspots is changing over time. You can study the Sun without binoculars or a telescope if you have a pair of solar eclipse glasses. Then you can easily see the largest sunspots. Such glasses are easy to buy on the Internet. Just make sure there are no scratches or holes in them. You can easily damage your eyes. With a device called a "solarscope," you can follow sunspots in a fun and safe way. A solarscope is a small foldable telescope that projects an image of the Sun onto a piece of white paper. A solarscope has many advantages. You do not need a solar filter, and you cannot damage your eyes. And several people can watch at the same time. A similar, but much sturdier, device called a "sunspotter" is also available.

A sunspotter is a simple and practical instrument that makes it easy to observe the Sun safely (NASA).

Eclipse glasses are very useful and can easily be obtained on the Internet (Astronomi.no).

Sometimes there are many large sunspots that can easily be observed without sophisticated instruments (Big Bear Observatory).

The Sun Seen from Your Backyard

If you plan to observe the Sun with a telescope or binoculars, you must NEVER look with your eyes unless you have a good-quality Sun filter in front of the telescope. You can buy such filters in most astronomy stores online. Again, it is important to make sure there are no scratches or holes in the filter.

A safer method is to use a telescope or binoculars and project an image of the Sun onto a white wall or a piece of white paper. One can create a shadow on the wall or on the paper by mounting a piece of cardboard around the telescope.

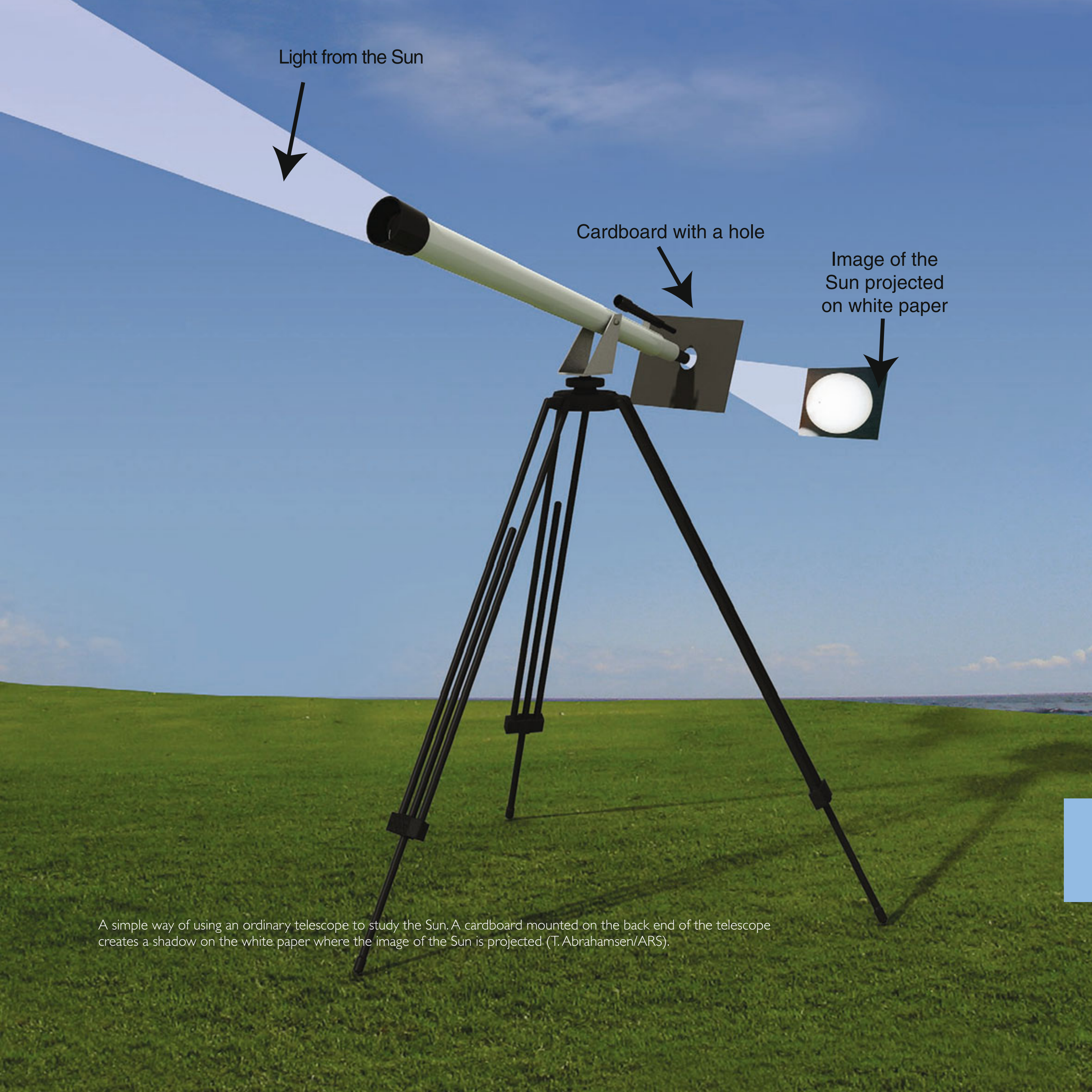
Projecting the Sun with a telescope is done by pointing the telescope toward the Sun without looking into it. An image of the Sun is formed at a distance behind the telescope when the telescope is pointing in the right direction. It can be a little bit hard to find the right direction. You know you are close when the shadow of the telescope tube is as small as possible. The distance to the paper/wall should be about 30–60 cm.

An effective method to create a larger image of the Sun is to close the curtains to make it dark inside and point the telescope toward the Sun through a crack in the curtains. Use a mirror behind the telescope to reflect the solar image onto one of the walls in the room.

Only if you have solar filter is it safe to look through the telescope. You can also buy specially made filters that can be adjusted to only show different layers of the solar atmosphere. These are called H-alpha filters and will show you filaments and prominences suspended outside the solar limb.

The Sun seen through a Coronado PST telescope, which comes equipped with a H-Alpha filter that allows you to observe part of the solar atmosphere. Here one can observe the spectacular prominences on the outside edge of the Sun (Astronominsk).

An example of a telescope equipped with a H-Alpha filter is the Coronado PST (Coronado).



A simple way of using an ordinary telescope to study the Sun. A cardboard mounted on the back end of the telescope creates a shadow on the white paper where the image of the Sun is projected (T. Abrahamsen/ARS).

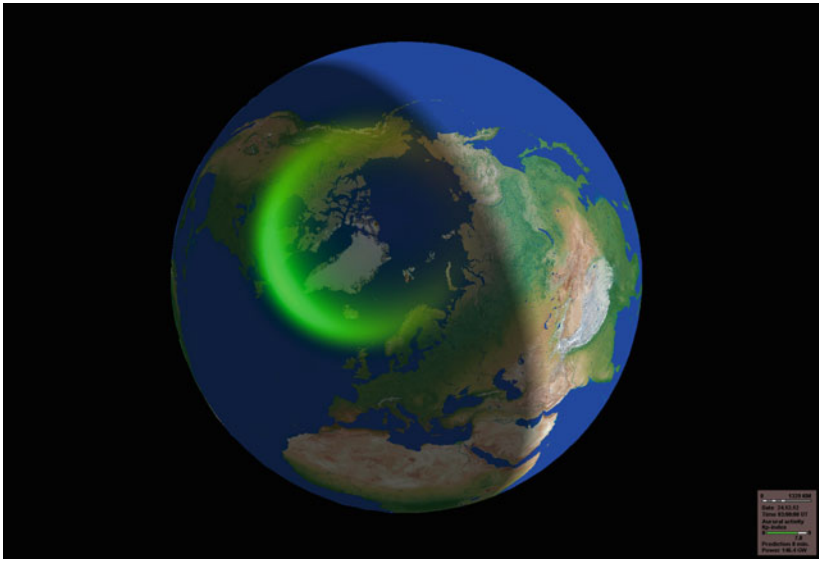
Where to See the Northern Lights

The northern lights are impressive and different from all other light phenomena in that they exhibit an amazing variety of colors, structures, and movements.

Auroras are present within a zone of about 1,000–3,000 km from the magnetic poles, both day and night during the entire year. However, auroras are only visible from the ground during clear, dark nights. Daylight will outshine the auroras.

The best place to see the auroras is, of course, at high latitudes. Also, one should travel in the winter when the nights are dark. The best period is between September and April. In the summer, the midnight Sun will make it impossible to see it. In Scandinavia, the strongest auroras often occur between 8 p.m. and midnight.

You should avoid city lights and find a dark place away from the city on a summit or open country with a clear view of the northern horizon. One should also avoid the full Moon, which makes the sky less dark.



It is possible to predict the location of the aurora based on the measured solar wind speed (F. Sigernes/UNIS).

In parts of northern Norway, you can see the northern lights almost every dark and clear night. In Fairbanks, Alaska, you can see it five to ten times a month, and along the US–Canadian border two to four times a year. In Mexico, you will only see auroras once or twice a decade.

By monitoring the activity on the Sun all day every day and measuring the speed of the solar wind particles, scientists can predict the strength and the location of the aurora. So by using the Internet, you can find web pages that provide aurora forecasting.

Photographing auroras by the water often adds a dramatic effect. Here, the Moon and auroras are reflected in the water in Ersfjorden outside Tromsø in northern Norway (F. Broms).

How to Take Pictures of the Aurora

Capturing the northern lights with a camera can provide a memory for a lifetime. Photographing northern lights is relatively easy, but for the best results some basic principles should be followed, and the more experience you gain the better your photography will get.

The best results are obtained with cameras that can be put in manual mode (M), where you can control shutter speed and aperture settings at the same time. This makes DSLR cameras best suited for aurora photography, and with most DSLRs, you stand a very good chance of getting some satisfactory aurora images in a short time.

When taking pictures of auroras, a tripod is absolutely essential. Pre-focus your lens at infinity and re-adjust if necessary. Make sure your camera is in M-mode. If you have a filter on your lens, remove it, as it usually causes undesirable concentric rings to appear on the images.

Fast lenses (f/2,8 or lower) with focal lengths of 10–35 mm are ideal. Whatever lens you have, set the lens to its lowest f-number and the ISO value fairly high. A good starting point is usually an exposure time between 8 and 30 s at ISO 800. At higher ISO values, image noise starts to become a problem, and finding a good balance between ISO value and exposure time is therefore often crucial. Adjust the settings depending on how your camera performs and use shorter exposures and/or lower ISOs for bright aurora displays.

Watching the northern lights can be a memory for a lifetime (F. Broms).

For the northern light pictures, the camera should be mounted on a sturdy tripod with a wide-angle lens. Including a foreground such as a house or a person often makes the image more interesting and alive. Auroras can appear quickly, so the key to taking a good image is to be prepared in advance (F. Broms).

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Aurora over the EISCAT antenna in Tromsø, Norway (H. B. Basemann).

MODERN RESEARCH ON THE SUN, THE NORTHERN LIGHTS, AND SPACE WEATHER

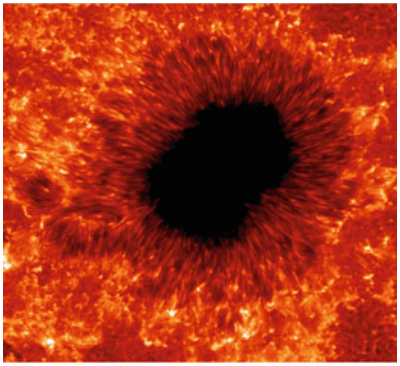
Modern Solar Research

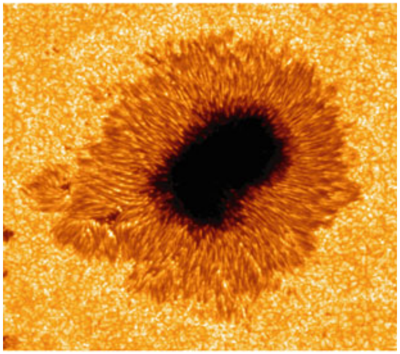
TODAY SCIENTISTS are using solar telescopes with sophisticated technology to improve the image quality and to correct for disturbances of Earth's atmosphere. This has been possible because of faster computers and deformable optical mirrors. The computers calculate the distortion from the atmosphere and then reshape the mirrors to cancel out the distortion.

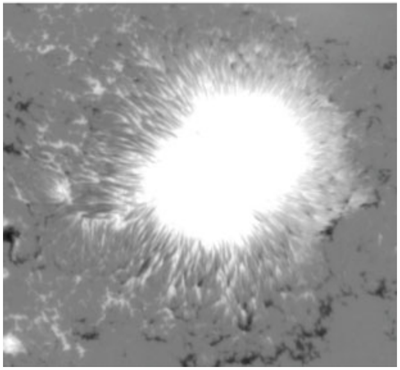
Space-based telescopes provide continuous monitoring of the Sun without disturbances from the atmosphere. Above the atmosphere one also gets access to the UV and X-ray emission from the Sun, which allows us to observe the dynamic solar atmosphere.

Superfast computers are used to run advanced numerical computer models to simulate the properties of the Sun and many of the observed features in the solar atmosphere. In this way, one can explore the Sun as a laboratory for fundamental astrophysical processes.

All the data from the ***Hinode*** spacecraft is stored at the European Hinode Data Center at the University of Oslo, Norway. Powerful computers make the data easily accessible for scientists all over Europe (ITA).







Sunspots are observed with telescopes and computers are used to model the physical processes (Hinode/ITA).

The science data from the Japanese satellite ***Hinode*** is downlinked to the Svalbard satellite station and transferred via a fiber optical cable to the Norwegian mainland. European users will obtain daily updated observations from the Hinode Science Center in Oslo (T. Abrahamsen/ARS).

Rockets Spear Through the Aurora

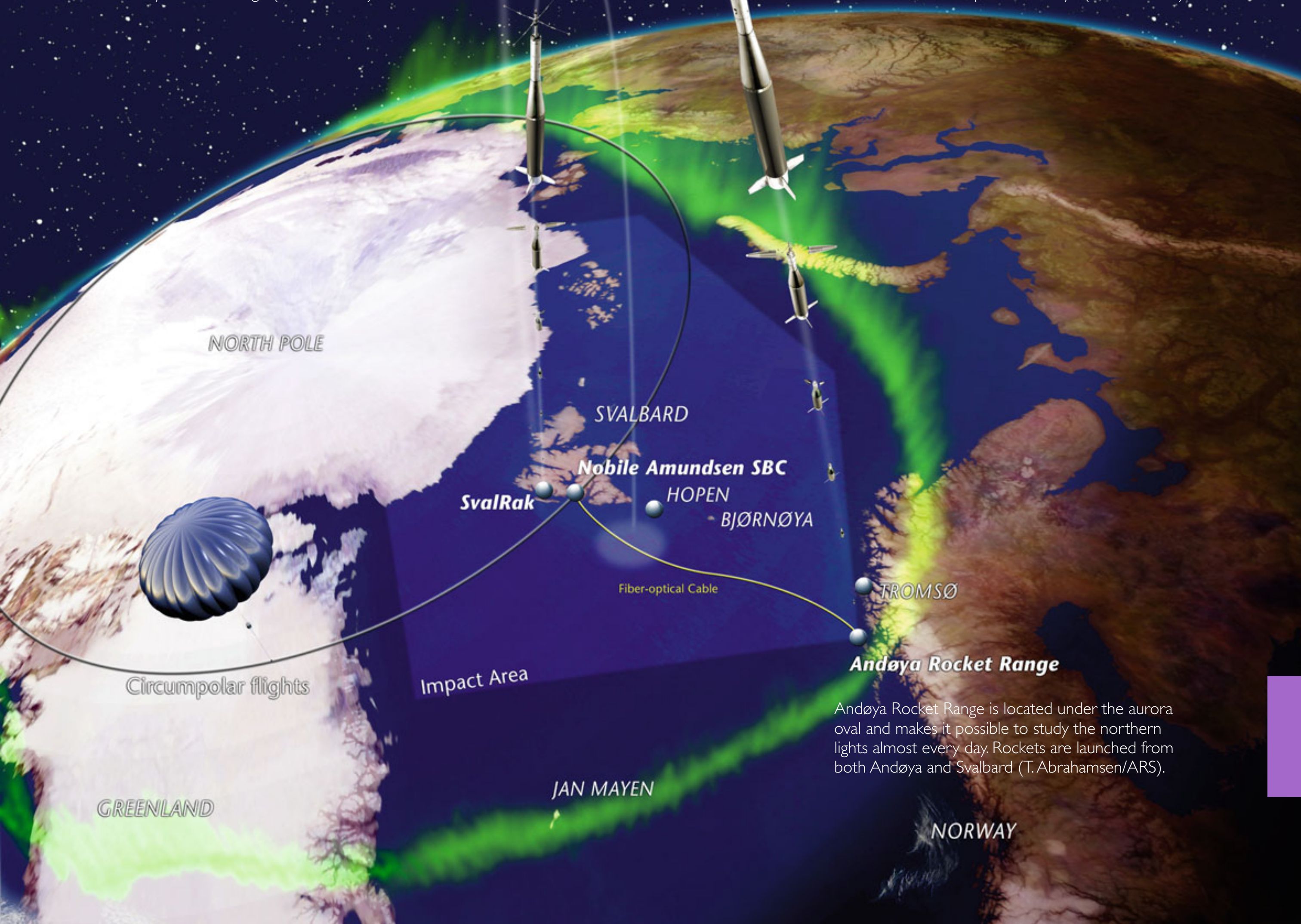
After the start of the Space Age, scientists began utilizing spaceborne instruments and cameras to study the aurora. A sounding rocket range was established on the northern Norwegian island of Andøya. It is the northernmost permanent rocket launch facility in the world and the first rocket launch there took place in 1962. More than 1,000 rockets have been launched since, many of them NASA rockets. Other launch facilities are located in Kiruna, Sweden, and Fairbanks, Alaska.

Instrumented rockets have contributed to our understanding of the aurora. The rockets used in the aurora experiments are normally 10–20 m long and typically carry an instrument load of 150–200 kg and extend to a height of 300–500 km. The altitude record from the Andøya Rocket Range is nearly 1,500 km. With rockets, auroras can be studied from the inside. Scientists are also using satellites to study the aurora from above and on a global scale.

Andøya Rocket Range with the city Andenes in the background (ARS).

Andøya Rocket Range (K. Dahle/ARS).

One of the launch pads at Andøya (K. Dahle/ARS).



Andøya Rocket Range is located under the aurora oval and makes it possible to study the northern lights almost every day. Rockets are launched from both Andøya and Svalbard (T. Abrahamsen/ARS).

Using Lasers to Study the Atmosphere

The ALOMAR (Arctic Lidar Observatory for Middle Atmospheric Research) is an international research station and part of the Andøya Rocket Range. Scientists from all over the world are using ALOMAR to explore and investigate the properties of our atmosphere by using very sophisticated laser and radar systems.

A special focus is on the interplay between the upper atmosphere, the radiation from the Sun, and the solar wind. At the edge of the atmosphere, we find Earth's "freezer." Even if the temperatures are quite comfortable at Andøya, 90 km above the ground it is colder than at the South Pole.

By using powerful light from lasers and radar, one can measure temperatures and densities and keep an eye on the world's highest clouds. These are called noctilucent clouds or night shining clouds. ALOMAR is also measuring dust particles from small meteors burning up when they hit Earth's atmosphere. In addition, they study the amount of ozone and other gases in the atmosphere.

ALOMAR observes most layers of Earth's atmosphere and gains important knowledge to also better understand the observed climate change. The observations from ALOMAR are also used to determine when to launch rockets into the atmosphere.

Powerful laser beams and radar are used to probe the properties of the atmosphere (G. Baumgarten).

The laser light from ALOMAR and the northern lights (K. Dahle/ARS).

The laser beams from the ALOMAR observatory explore Earth's atmosphere (K. Dahle/ARS).

The Kjell Henriksen Observatory was opened in 2008 and contains 32 rooms, each with a glass dome where scientists can place their scientific instruments (KHO/UNIS).

The Aurora Observatory at Svalbard

Kjell Henriksen Observatory at Svalbard, Norway, is the world's most modern aurora observatory. Svalbard is located under what we call the magnetic cusp, a kind of funnel in Earth's magnetosphere where solar wind particles can enter and create what we call the dayside aurora.

The observatory has 32 rooms, each with a glass dome that the instruments can view the aurora through. Scientists from all over the world can rent "a room with a view" at the observatory and remotely control their instruments from their home institution.

To study the ionosphere, large radar antennas at Svalbard, Tromsø, and Kiruna (Sweden) are used. One antenna transmits strong radar signals up into the atmosphere, while the other registers the reflected signals. This is like a sophisticated police radar. The data provide information about the structure of the atmosphere and how this changes after solar storms.

One of the large EISCAT antennas at Svalbard with the aurora as a backdrop. One antenna transmits strong radar signals up into the atmosphere while the other antenna registers the signals reflected from the atmosphere. Kind of a sophisticated police radar (N. Gulbrandsen).

The students posing with the rocket they built during Space Camp (Space Camp).

Space Camp

Each year a group of European students (17–19 years old) meet at Andøya Rocket Range to learn more about the Sun, the atmosphere, and the aurora. After a week, they are among the few that can call themselves real rocket scientists.

The goal of Space Camp is to let the students take part in real science. They get to work with the same tools as real rocket scientists. Tutors from Norway, the European Space Agency (ESA), and NASA guide the students while they construct their own instruments to take measurements in the atmosphere. The highlight is launching their instruments on a self-built rocket.

The students are building the electronics that will do measurements during the rocket flight (Space Camp).

The launch of a student rocket from Andøya Rocket Range (Space Camp).

Useful Resources

There are many very good web sites with useful information about the Sun and the aurora.

Solar and Heliospheric Observatory
Updated images of the Sun, large archive of images and useful links
http://soho.nascom.nasa.gov

Solar Dynamics Observatory
The new super-telescope in space with daily updated images
http://sdo.gsfc.nasa.gov/

spaceweather.com
A very useful site with news about upcoming aurora, meteor showers, etc.
http://www.spacewetaher.com

ESA 4 European Space Agency
http://www.esa.int

NASA – National Aeronautics and Space Administration
http://www.nasa.gov

Andøya Rocket Range
http://www.rocketrange.no

Aurora Observatory at Svalbard
Kjell Henriksen Observatory with a nice aurora forecasting map
http://kho.unis.no

Norwegian Space Centre
http://www.spacecentre.no

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Spectacular "sunset" over Earth's atmosphere as seen from the space shuttle (NASA).

About the Author

Pål Brekke received his Ph.D. in 1993 from the University of Oslo. He studied the dynamics of the solar atmosphere from instruments on sounding rockets and the space shuttle *Challenger*. Since 1993 he has participated in the Solar and Heliospheric Observatory (SOHO), a collaboration between ESA and NASA. After the launch of SOHO in December 1995 he was part of the science operation team at NASA Goddard Space Flight Center (GSFC). In 1999 he joined ESA as the SOHO Deputy Project Scientist stationed at GSFC. He was also involved in outreach and media activities, making SOHO one of the most well-known current satellite projects. He is now a Senior Advisor at the Norwegian Space Centre.

Dr. Brekke received a Fulbright Fellowship in 1994, ESA's Exceptional Achievement Award in 2002, and Laurels for Team Achievements from the International Academy of Astronautics in 2003.

P. Brekke (NRS).

Solar storms can affect our technology based society (NASA/J. Rumburg).

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