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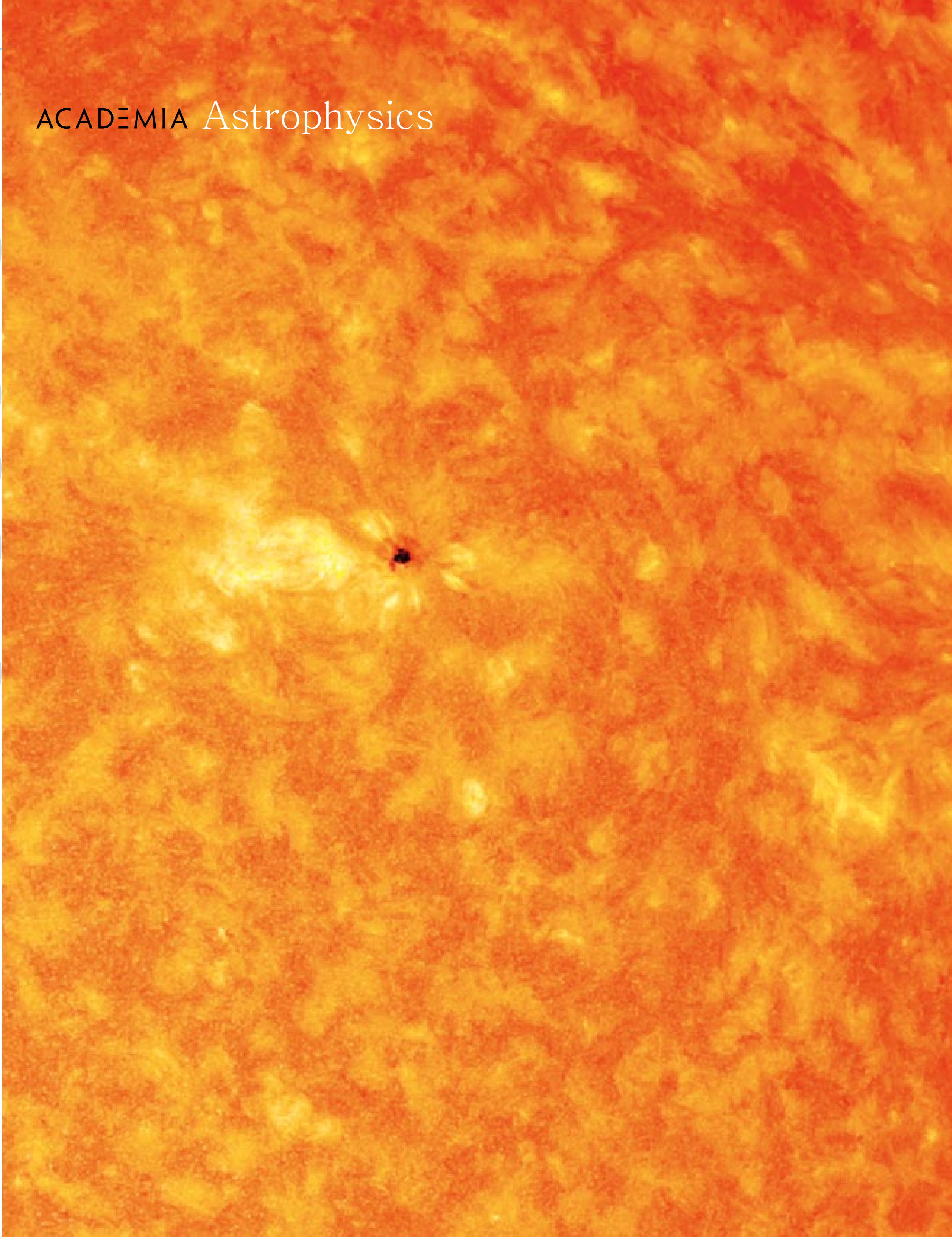
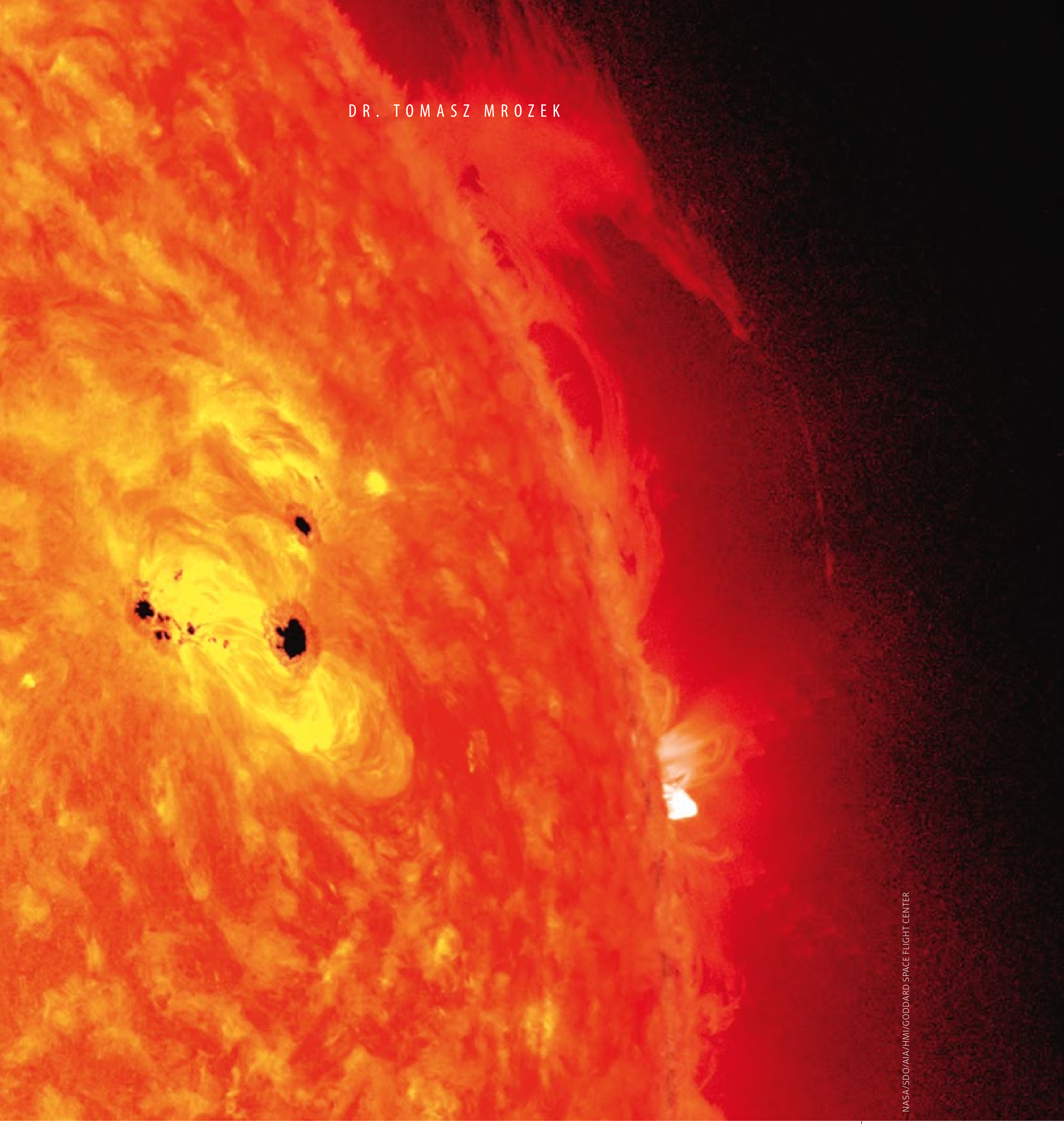


Searching for Sunspots

DR. TOMASZ MROZEK



Astronomers who work during daylight hours focus on observing sunspots. Why are they keeping a close eye on them right now in particular?

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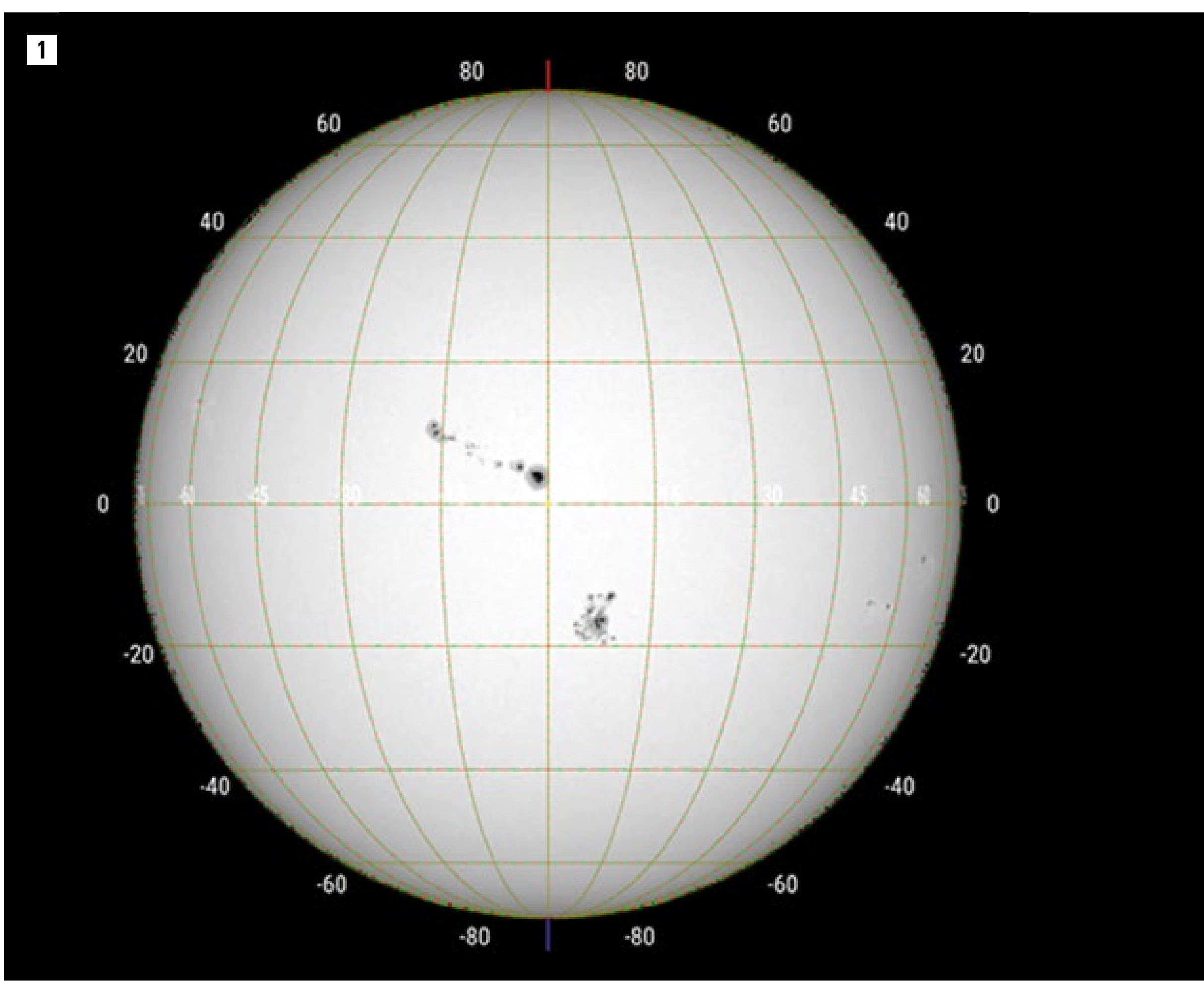
In his short treatise *Sidereus Nuncius*, published on 13 March 1610, Galileo described discoveries he made during a few weeks of observations of the night sky using his latest invention: the telescope. He described mountains on the Moon, myriad previously unseen stars, moons of Jupiter and phases of Venus – objects and phenomena which now seem obvious but which, at the time, revolutionized scientific thinking, gave rise to modern science, and turned natural order as it had been described by Aristotle almost two millennia earlier upside-down.

Oversight

However, Galileo did not turn his attention at least one important celestial object, or if he did – as we might say today – he failed to properly publish his results. Almost exactly a year after the publication of *Sidereus Nuncius*, on 9 March 1611, the Dutch astronomer Johannes Fabricius turned his own telescope towards the Sun and noticed several dark regions. He called in his father David Fabricius, and the two of them, paying no heed to the pain caused by gazing directly at the Sun, continued their observations as the star rose ever higher above the horizon. They soon abandoned their telescope in favor of a camera obscura, and noticed that the dark spots seem to be attached to the Sun's surface and change position as it rotated on its axis. They published the results of their observations three months later in *De Maculis in Sole Observatis, et Apparente earum cum Sole Conversione Narratio*.

They were hailed as the discoverers of sunspots, even though they certainly were not the first to have observed them. The scientific community has a tendency to proclaim the first person to describe a certain phenomenon in writing as its discoverer, but the fact is we now know that sunspots had already been observed without telescopes all around the globe for at least two thousand years. Historical ob-



servations were relatively rare, since sunspots visible to the naked eye appear infrequently. However, the record of pre-telescope observations is so extensive and covers such a long period, that we are now able to identify periods when reports of sunspots were more common.

The higher the number and the larger the size of such spots, the higher the activity of the Sun. This means that the historical observations made without telescopes provide an incredibly important insight into periods of heightened solar activity in the past. Why are they important? Because they are closely linked with conditions prevailing here on Earth at the time. But more on that later.

Don't try this at home!

Even at its lowest point above the horizon the Sun emits extremely powerful light, and modern telescopes, even the cheapest, are far more effective at focusing light than the instruments used by Johannes Fabricius. Attempting to look directly at the Sun for a just few seconds dramatically increases the temperature within the eye, which can lead to permanent loss of sight.

Motion

The source of solar activity is lies deep within the star. At a distance of around 0.7 of the Sun's radius from the center, we find the tachocline – the region where the Sun no longer rotates as a rigid solid. From that level up to the surface, the matter making up the Sun rotates at different speeds: the fastest around the equator, the slowest at the poles. This effect, known as differential rotation, is crucial in bolstering the star's magnetic field. The other type of motion observed between the tachocline and the surface is the upward movement of gas caused by convection – the dominant energy-transport mechanism in the Sun's outermost layers. The mechanism is exactly the same as that observed in a pot of soup on a burner. As heat is applied, the lower layers of the liquid rise to the surface, give off heat and sink to the bottom again as

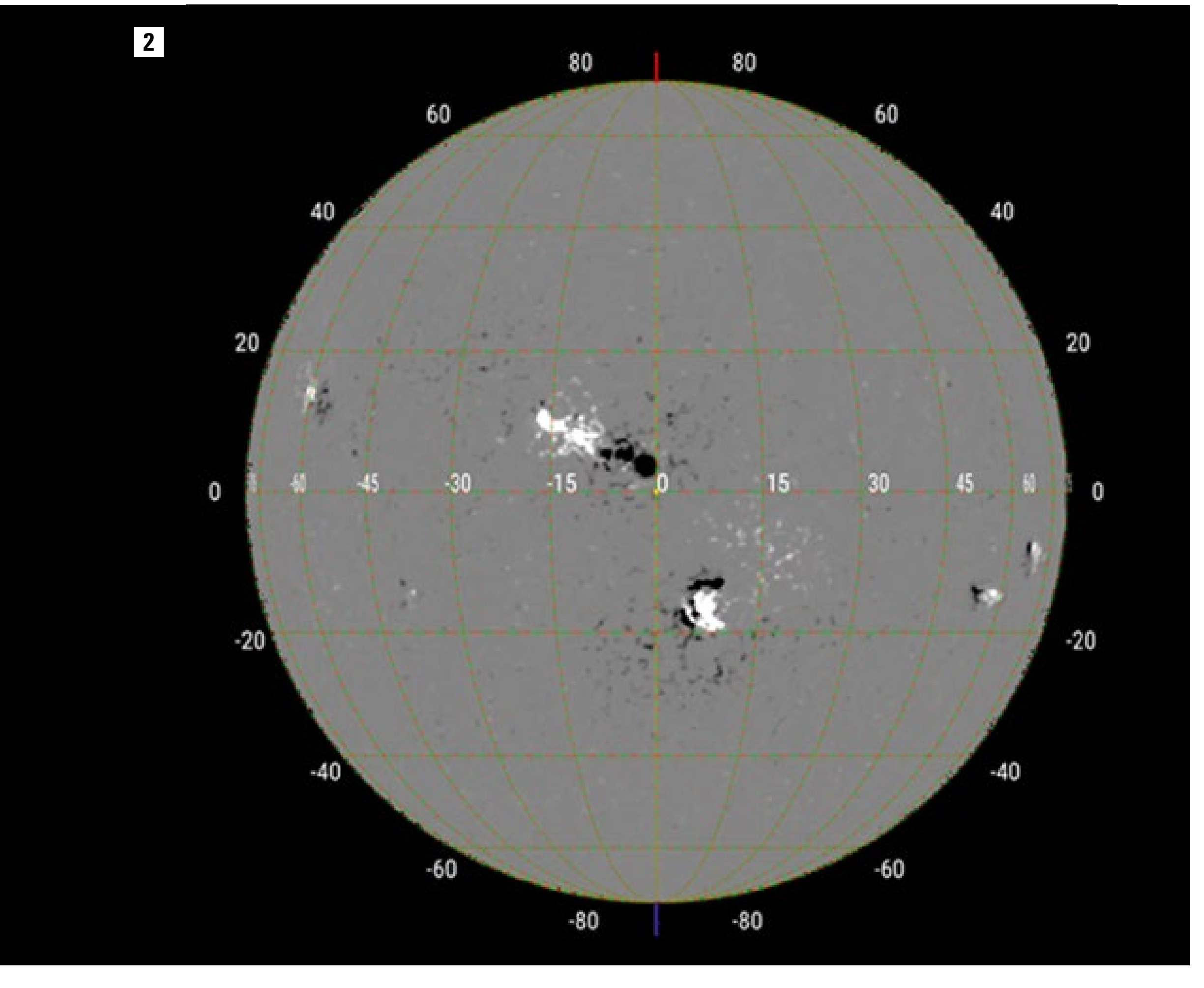
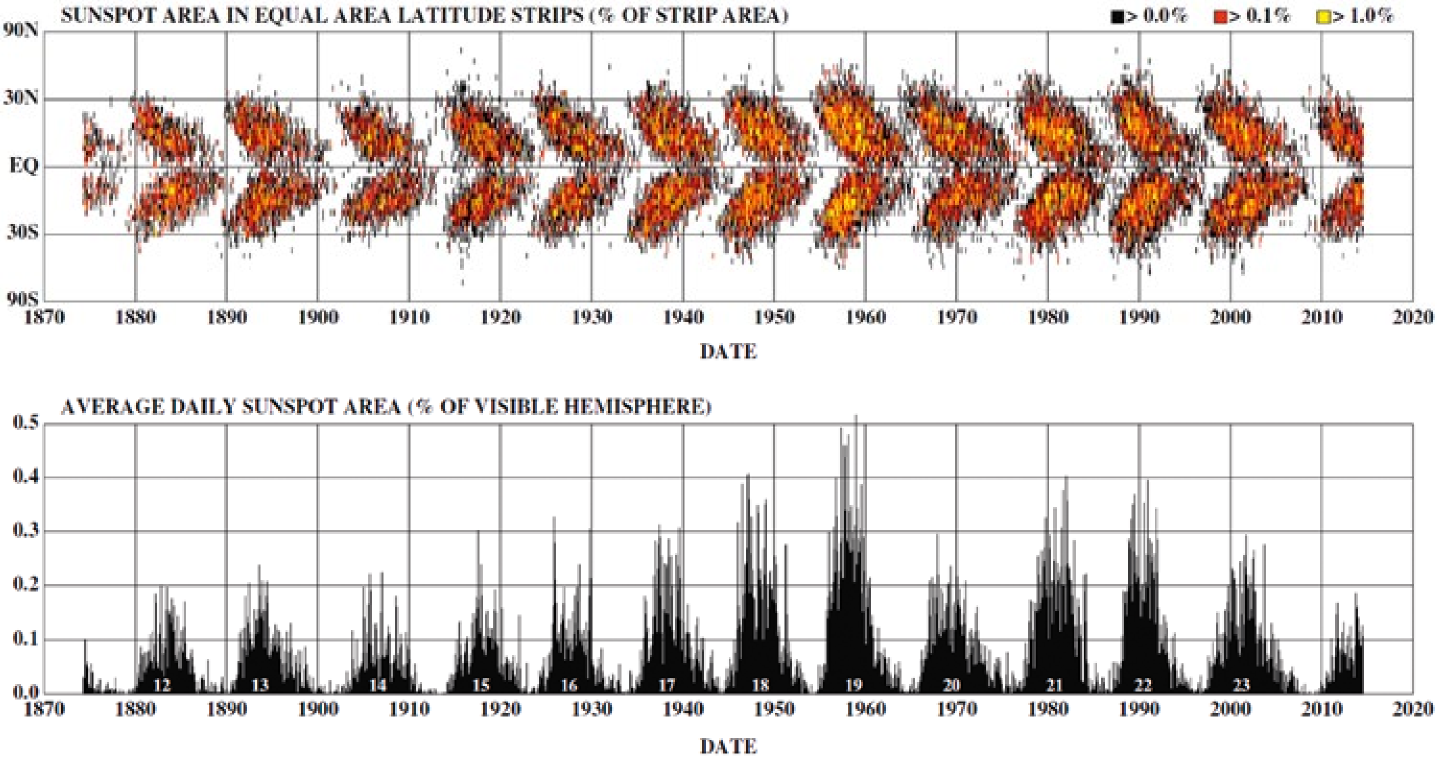


Fig. 1.
Solar photosphere with sunspots. Magnetic field measured in the photosphere at the same moment.

Fig. 2.
The pale regions are north poles (positive, lines "exiting" the Sun), while the dark regions are south poles (negative, lines "entering" the Sun).

Both photos have been superimposed with a grid of heliographic coordinates (north pole at the top, west on the right). The magnetic layout of the dark regions known as sunspots is clearly visible.



The top diagram, known as a butterfly diagram, shows the heliographic latitudes where sunspots were observed between 1874 and 2014. The bottom diagram shows the variation of solar activity measured as the total surface of sunspots observed during the period (Hathaway 2015).

they cool. We can see this by placing pieces of carrots or potatoes in the soup: the vegetables rise to the surface and sink to the bottom, carried by bubbles of heated liquid. In the Sun's convection layer, the role of the carrots is played by the magnetic field, strongest around the tachocline, which rises together with hot gas to the "surface" or the photosphere – the lowermost solar atmospheric layer. This causes the appearance of dark regions, around 1000–1500 degrees kelvin cooler than their surroundings, in areas where this powerful magnetic field limits the effect of hot gas from the Sun's interior.

Magnetic poles are clearly visible within each spot, and they have a fascinating property: in the given cycle of activity, the poles in spots on the given hemisphere are always arranged in the same direction relative to the Sun's rotation (east-west). For example, towards the end of the active cycle in the northern hemisphere, the magnetic poles of sunspots are arranged such that the south pole is slightly further west, with the north pole "trailing" behind. The situation is reversed in the southern hemisphere: the north pole is slightly ahead, with the south pole trailing behind.

The level of solar activity is conventionally measured by counting spots (s) and groups of spots (g) using the equation $R = k(10\,g + s)$. It was first proposed by Rudolf Wolf in the 19th century, where R is the relative sunspot number and k is the personal reduction coefficient. Today we also use other ways of measuring solar activity, such as the total surface area of spots visible on the Sun's surface on a given day. Regardless of which method we use, however, the values vary across an eleven-year cycle. Interestingly, the polarization (the order in which the magnetic poles of sunspots are arranged, east-west) changes from cycle to cycle. For example, if during a given cycle the magnetic fields of sunspots in the northern hemisphere are arranged such that the south pole is further west than the north pole, then during the following cycle the situation is reversed and the north pole will be further west. This is why we talk about 22-year cycles, since it takes that long for the configuration of pole direction of sunspots within each hemisphere to repeat.

Another interesting variation observed during each cycle of solar activity is that at the start of each cycle, spots are visible at higher heliographic latitudes (nearer the Sun's poles) than spots which appear at later stages of the cycle. You could say that as they "age", sunspots tend to progress towards the equator.

Heated lower layers rise up to the surface, they give off heat and sink to the bottom again once they cool down. The effect can be seen, for instance, by watching potatoes in a pot of soup.

Cycles

Knowing the characteristics of individual stages of the solar activity cycle allows us to recognize spots heralding the start of the next cycle. As a cycle comes to an end, we start looking for regions appearing at high latitudes. They usually present as small individual spots or clusters of tiny spots. As well as noting the location where the new cycle begins, it is important to determine the polarization of the magnetic field around the spots, which should have a reverse polarization to the cycle coming to an end. If we are able to register such a region, we can state that it marks the beginning of the next cycle. The Sun is currently in the final stages of the 24th cycle. Astronomers have been eagerly awaiting the beginning of the next cycle and looking out for spots heralding its start.

The first sunspot which seems to form a part of the new cycle appeared on the southern solar hemisphere on 9 April 2018. It was found at a high heliographic latitude and it has the opposite polarization to that of the previous cycle in the same hemisphere. In spite of its short lifespan, lasting less than 24 hours, the region also produced a flare, making it a fully active region. Such observations are conducted by state-of-the-art observatories in Earth orbit. One such tool is the Solar Dynamics Observatory (SDO) satellite, carrying the Atmospheric Imaging Assembly (AIA). The AIA is a set of four telescopes conducting concurrent observations of the Sun using different filters, allowing us to monitor a vast range of phenomena taking place in the solar atmosphere. The AIA generates images of the entire visible surface of the Sun with an incredibly high spatial resolution (a single pixel represents 0.6 seconds of arc, or approx. 400 km on the Sun's surface) and temporal resolution (images are taken every 12 seconds). This produces a vast stream of data of up to 1.5 terabytes per day! All the observations are available to view online at https://helioviewer.org. You can also install the helioviewer app (available from http://www.jhelioviewer.org/), which includes all the observations made by the AIA. It allows users to follow solar activity and its variation, explore the range of phenomena of solar activity and look for signs of a new cycle, all from the comfort of their own homes. Spotting the signs of a new cycle and even observing brand new phenomena is genuinely within reach of any careful observer. You need to be patient and diligent, and then channel your inner Fabricius to make sure you publish your results before anyone else does.

Anticipations

Why are astronomers so keen to spot the signs of the next cycle? Because they are not entirely sure that it will actually happen! It might sound like a joke, given that we have been observing regular cycles since the eighteenth century, but it has not always been the case. Additionally, individual cycles have different numbers of spots of different sizes, and different numbers of powerful flares and other activities. The 23rd cycle was followed by the longest period on record with the lowest sunspot activity, with no sunspots observed for several months. The 24th cycle has been the weakest in recent decades, and all signs indicate that we are on course for another period of minimal activity. We await the start of the 25th cycle but we cannot predict what it will be like or even whether it will happen at all. Every cycle is different; for example, hardly any sunspots were observed during the second half of the 17th century.

> More numerous and larger sunspots mean higher solar activity, which is clearly linked to the conditions prevailing on Earth.

This would be of no concern if it were not for the fact that historical sources reveal that periods of the lowest sunspot activity during the 17th century coincided with exceptionally harsh winters. For example, we know that the Thames froze over regularly and Londoners held markets on the river ice. The Gulf of Finland also froze regularly, which meant that for several months of the year traders rode horses over the frozen sea from Tallinn to Helsinki, stopping at temporary inns along the way. On the other hand, records from the 9th, 10th and 11th centuries abound with information about sunspots observed with the naked eye, which means that the level of activity must have been significantly higher. Historical records from the period mention widespread cultivation of grapevines in Poland and Viking settlements in Greenland, which indicates a much milder climate in the northern hemisphere.

There is clearly a link between solar activity and average temperatures on Earth, although we are only just beginning to understand it. Perhaps the next solar cycle – or its absence – will help us learn more about the links between the Sun's activity and climate on Earth.

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Further reading:

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