Chapter 2

How to See the Sun

Observation: The Sun, the solar corona, auroras
Significance: Astronomy beyond the visible, the rotating Sun, solar wind
Science: How the Sun works, sunspots

The Sun is a star, and all stars are suns. The word *Sun* is the name we give to our local star. Its first recorded use in English comes from the hand of King Alfred in the ninth century, but most Indo-European languages have similar-sounding words for it based around a root syllable *su-* or *so-*. We have been talking about the Sun for a long time.

The Sun is, right now, the most important thing in your life. Its power created the Solar System, and its gravity holds it together. It is far and away the largest astronomical body in our local environment. Just 150 million kilometers away and 1.4 million kilometers across it dominates the daytime skies. With the correct apparatus, it reveals an awesome glory. We can watch its power at work.

In this chapter we will, after taking due precautions, observe the Sun. We will also see how those observations have changed history. It was upon the face of the Sun that astronomers saw blemishes, spots that overturned another element of the ancient view of the heavens and demonstrated that the Sun was in motion. It was by dissecting sunlight that astronomers first stretched the boundaries of their science beyond the visible. It has been by identifying and studying the solar wind that we have been able to understand our Solar System as the realm where the Sun's power rules.

These have mostly been quiet revolutions. When Galileo saw the moons of Jupiter, it was obvious to many that the classical account of the sky was incomplete. The same was true for sunspots, which provoked a furious debate in the seventeenth century. But spectroscopy, the dividing of light, and the nature of the solar wind are huge advances in the human understanding of our world that have remained hidden. Seeing the Sun is a chance to make them shine.

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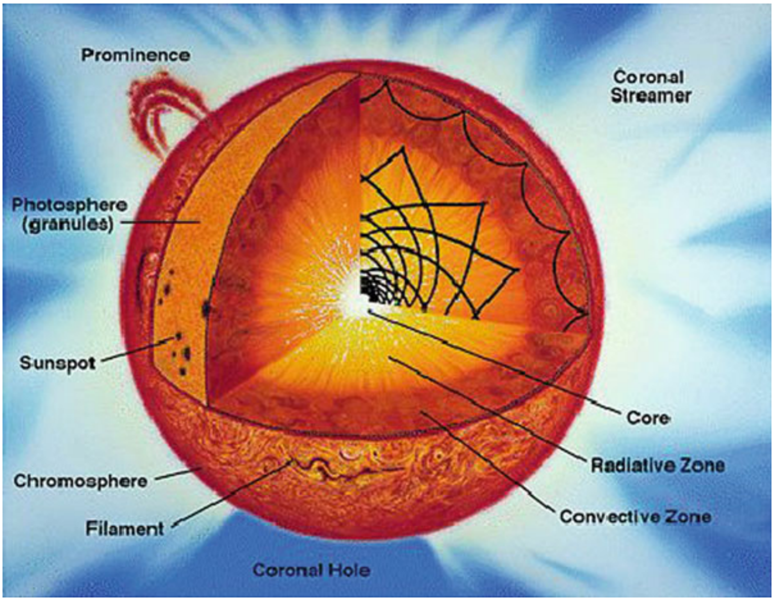

Fig. 2.1 A cutaway diagram showing the structure and zones of the Sun (Credit: NASA)

How to Look at the Sun

Here is a basic rule – don't look at the Sun.

To put it more precisely – don't observe the Sun using any telescope, binoculars or other optical instrument that has not been fitted with a safe appliance that is specific to solar astronomy. Don't stare at the Sun with your unaided eyes, unless you are using a recognized and tested solar filter. Why? Because human sight is precious and fragile, and the Sun can cause immediate and irreversible damage to the eyes.

This means avoiding home-made pieces of smoked glass, color film or whatever else seems like a clever idea and isn't. This means never using photographic solar filters as a sunshield for the eyes because, as their name suggests, they are for cameras.

This means, above all, not taking risks. If you are unsure of a piece of equipment, then do not use it to look at the Sun.

If you observe these warnings, then solar observing will become one of the pleasures of astronomy. Daytime viewing can be plagued by weather, but the Sun is much more available than any other astronomical target. It is also changing all the time, and we can see that for ourselves. This is rare in astronomy, where the timescales are usually far longer than the span of many human lives. The Sun provides a chance to understand and use fantastic online data provided by satellites that are watching it all the time. Finally, learning about the Sun informs our observations of other, much more distant stars.

In this chapter, we are going to explore the Sun using each of the safe ways open to amateur astronomers. We will examine white light, hydrogen alpha, coronal and auroral observing, looking first at how to make the observation and then at what it reveals. This way, we will build up a practical picture of what we know and also what we don't know. The bright Sun reveals everything else, but hides itself.

Looking at Sunlight

In 1800, the great astronomer William Herschel (1738–1822), whose work with his sister Caroline (1750–1848) brought about huge changes in our understanding of the Solar System, used a prism and a thermometer to show that the Sun's heat extended beyond visible light. It was a simple experiment, easy to repeat at home. It was a small step in the wider search for the nature of light, a demonstration that the visible was not all that light contained.

The modern analysis of starlight began with Isaac Newton (1642–1727), a towering figure in the history of science to whom we will return in later chapters. He observed in 1666 that sunlight could be divided into a continuous spectrum, the rainbow. It was Joseph Fraunhofer (1787–1826) who identified dark gaps in the Sun's spectrum. Working at his optical factory near Munich, he used a 25 mm telescope to observe (with care) the Sun, writing: "I found with this telescope almost countless strong and weak vertical lines."

Looking at white light divided into its colors, Fraunhofer identified 10 of these strong lines and as many as 570 faint ones. In 1814, he was able to draw some 350 of them in all.

Later, he extended this search to stars beyond the Sun. He looked at Betelgeuse, the red alpha star of Orion, finding there yet more "countless fixed lines which, with a good atmosphere, are sharply defined." Even more significant was what he found in the brightest star of all, Sirius: "I have seen with certainty in the spectrum of Sirius broad bands which appear to have no connection with those of sunlight."

The Fraunhofer lines found in the Sun were studied intensively over the nineteenth century. Gustav Kirchhoff (1824–1887) identified that one of the bands was related to the element sodium. He later produced his laws of spectroscopy that distinguished between the different kinds of spectrums.

Spectroscopy allows us to peer into the chemical contents of the Sun and stars. It enabled the discovery that unlocked the secret of the Sun's power.

Finding Helium

A quick glance at the Periodic Table shows two elements at its peaks. One is hydrogen, the most prevalent element in the universe. The other is helium, identified in the nineteenth century by looking at Fraunhofer lines in the Sun.

The discovery of helium is credited jointly to Pierre Jules Janssen (1824–1907) and Norman Lockyer (1836–1920). Janssen made the journey from France to Andhra Pradesh in India to observe the solar corona, and he identified a dark absorption line never seen before. He thought it might be an unknown element lodged within the Sun and sent a communication to this effect to the Academy of Sciences in Paris.

By coincidence, the same October 1868 meeting of the Academy had a report announcing the same discovery from the British astronomer Norman Lockyer. Janssen might have saved himself the trip, for Lockyer had identified the unknown absorption line while observing from West Hampstead in London. The new line was quite near two familiar lines, D1 and D2, the fingerprints of sodium, but it could not be reproduced in the laboratory. Lockyer also proposed that the D3 line represented a new element.

This was a controversial suggestion. New elements with names such as asterium and coronium were being proposed in the scientific literature of the time, and one alternative theory was that D3 represented hydrogen but under extreme pressure and temperature. The existence of what became known as helium was not accepted until 1895, when William Ramsay and Morris Travers isolated it from gases given off by uranium minerals.

Lockyer also established the journal *Nature*. The first issue stated that it aimed to "place before the general public the grand results of scientific work and scientific discovery; and to urge the claims of science to move to a more general recognition in education and in daily life." This and his other many achievements led to his being gently lampooned:

> And Lockyer and Lockyer
> gets cockier and cockier;
> For he thinks he's the owner
> of the solar corona.

The White Light of the Sun

What makes the Sun shine? The Sun is in one sense insubstantial, a luminous ball of plasma without any solid surface. It is concentrated and very dense at the center, where the heat and pressure are so great that atoms of hydrogen collide with one another in a process known as nucleosynthesis or, more familiarly, fusion. First proposed in the 1920s by Sir Arthur Eddington (1882–1944), it was Hans Albrecht Bethe (1906–2005) who established a sequence of chemical reactions taking place to convert hydrogen protons via several stages into helium, the Proton-Proton (PP) chain. This releases a huge amount of energy that flows outward from the Sun's core to the edge and emerges as visible light. This white light of the Sun is what we see every day. It is white because it contains all the colors of the spectrum.

"Direct the telescope upon the Sun as if you wanted to observe it," wrote Galileo. "The further the paper is removed from the tube, the larger the image will become and the better the spots will be depicted, and without any injury one will see all of them."

It is possible to observe the white light of the Sun. The warnings with which this chapter started are serious, though, and no observation of the Sun should begin without taking all proper precautions. The Sun in white light can be safely observed with either a dedicated white light solar telescope or a safety-tested commercial (not home-made) adapter attached to a nighttime instrument, or by projecting the Sun's image onto a screen. Once again it must be done with care – care for the telescope, care for the screen and above all care for those observing. Never look directly at the Sun through a telescope's eyepiece.

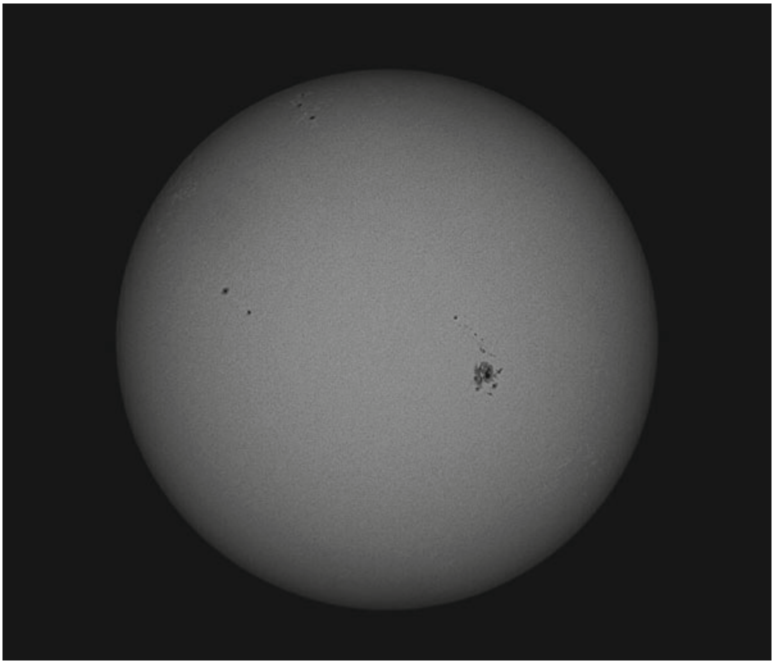

Fig. 2.2 The Sun in white light on May 12, 2012, taken with Baader solar film (density 5.0) with Canon 40D fitted with a Baader Solar Continuum filter, all through a Celestron ED80 Scope mounted on an Astrotrac (Credit: Stephen Devine, www.urban-astronomy.com)

The image produced by these methods reveals something like this. We are observing the solar photosphere, a white-gray environment punctured, especially in latitudes towards the Sun's equator, by the distinctive dark marks of sunspots.

These are the outer signs of intense and violent magnetic activity within the solar mass. They are areas of reduced temperature, a 'mere' 3,000 or so degrees of heat, but often many thousands of kilometers across. Sunspots begin life in latitudes to the north and south of the solar equator – we'll assume here that north and south represent compass points analogous to those on Earth – in activity belts where they are the product of a complex interplay of magnetic forces working through the various different rotations on the surface and within. Different areas of the Sun rotate at different speeds, creating twists and buckles in the magnetic fields. A sunspot probably comprises twisted rope structures wherein these magnetic forces are impeding energy from reaching the surface. Sunspots always move towards the center of the solar disk, changing all the time.

As you observe sunspots safely, you might start to notice light bridges that come to divide the dark umbra of a sunspot into two and also faculae (singular, *facula*), bright points near a sunspot where energy is escaping.

At solar minimum, sunspots form around, and rarely beyond, latitudes of 45 °. As the Sun moves towards solar maximum, the period of its peak magnetic activity, the sunspots move, as we observe, towards the center. This waxing of solar activity lasts 11 years and the full cycle of sunspot activity – the Schwabe Cycle, identified by Samuel Heinrich Schawbe (1789–1873) and recorded by Rudolf Wolf (1816–1893) – is therefore completed in 22 years.

White light observing reveals the power of the solar cycle. If you look at or near a well-developed sunspot, taking the precautions indicated above, you may be fortunate enough to observe a patch of temporary brilliance, perhaps half as bright again as the rest of the photosphere. These are white light flares – D, E and F-type sunspots as classified in the Zurich-McIntosh system are especially prone to them. They are brief but spectacular markers of the forces within.

A Funeral for Pseudo-Philosophy

Sunspots matter. First seen by Chinese observers, their existence led to one of the fundamental debates of early modern astronomy. It was a battle over how the universe, and science, should work.

On one side was the Jesuit priest-scientist Christoph Scheiner (c.1573–1650), who in March 1611 made use of a heavy mist to observe dark spots upon the bright orb. He returned to the same observation later in the year, shielding himself from the solar glare using stained glass. While his methods are not recommended, his observations were important. He wrote three letters describing his discoveries and had no doubt what he was seeing. “I have always considered it inconvenient to place spots… on the bright body,” he states, before advancing his argument that they were bodies transiting in front of the Sun, little planets like Mercury or Venus:

> “I do not think, therefore, that they are real spots, but rather bodies partly eclipsing the sun, namely stars located either between the sun and ourselves or revolving around the Sun.”

This conclusion freed the Sun from blemishes. Scheiner was protecting the idea that the heavens were both perfect and unchanging. “We saw what we were looking for,” Scheiner wrote tellingly a little later – all was well with the cosmos.

Galileo disagreed. He, too, was observing sunspots, and in a letter of 1612 he announced his intention to debate them, for: “Sunspots should bring about the funeral, or rather the extreme and last judgment, of pseudo-philosophy.”

Galileo had no time for Scheiner’s views. “Continued daily observations show me,” he wrote, “with every conceivable confirmation and no contradiction whatsoever, that my opinion squares with the facts.” These were, he argued, spots that resided on the surface of the Sun. His was a case based upon observation and also geometry. It was the simple solution, requiring no intermediate unknown bodies. "The spots are contiguous to the surface of the sun, and are carried around by its rotation."

Sunspots revealed an imperfect Sun. They also showed that the Sun was itself in motion. It is exciting still to observe the motion over time of sunspots, but in the seventeenth century it was to effect a revolution. Gone were the immobile upper spheres of the sky. In place of a philosophy hallowed by antiquity and authority, Galileo was proposing the primacy of observation. Scheiner had seen what he wanted to see. Galileo had just seen.

The Boiling Sun

Our second solar observation takes us beyond the experience of Galileo and Scheiner and into the chromosphere.

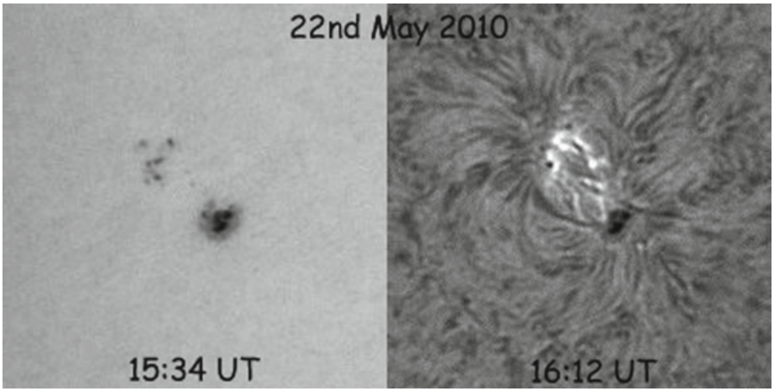

Fig. 2.3 A sunspot compared. Images of AR1072 in white light (*left*) and hydrogen alpha (*right*) from 22 May, 2010 with an 80 mm refractor and Baader solar filter for the WL image and a Coronado PST for the hydrogen alpha together with an Imaging Source monochrome DMK AU03 camera, images processed using RegiStax (Credit: Peter Meadows, www.petermeadows.com)

A hydrogen alpha telescope enables observers to explore the solar chromosphere, which lies above the white light photosphere. This is a zone both more tenuous and more transparent than that which we observe at white light, some 2,000 km thick and with an average temperature of around 10,000 K. The chromosphere contains no permanent features, its mottled patterns forever changing as convective currents rise and peak and fall. It's in the chromosphere where observers spot solar flares, sudden and massive releases of the energy stored in the Sun's magnetic field.

Hydrogen alpha telescopes use etalons, devices with parallel reflecting plates that reflect off unwanted wavelengths and, in their modern form, eliminate more than 99 % of the Sun's light. The name etalon was applied to the device by its creators, Charles Fabrey and Alfred Perot, in 1897 (Fabrey was later a co-discoverer of the ozone layer) and is taken from the French *étalon*, literally meaning *standard*, as in a standard unit of measurement. The other English word derived from *étalon* is stallion, the stallion being, I suppose, a standard horse. It's an odd combination.

It is worth taking any opportunity to observe at this or other wavelengths that reveal the chromosphere. There are prominences, which are graceful, almost balletic in the way they curl. Something about them inspired the Menzel-Evans scheme that labels features in this zone to abandon dry codes in favor of descriptive nouns. You can spot hedgerows or coronal rain, funnels, loops, surges and puffs. There are even jets and tornadoes.

The Wind in Our Hair

Perhaps the greatest revelation of solar power, though, comes when we have an opportunity to observe the Sun's corona.

The first way that this can be done safely is during a solar eclipse. The Moon, perfectly in line between the Sun and Earth, shields us from the white light photosphere such that it becomes possible to see the corona's streamers and rays. But total eclipses are rare events, and so in the early 1930s the French astronomer Bernard Lyot created an instrument to impose an artificial moon in between the Sun

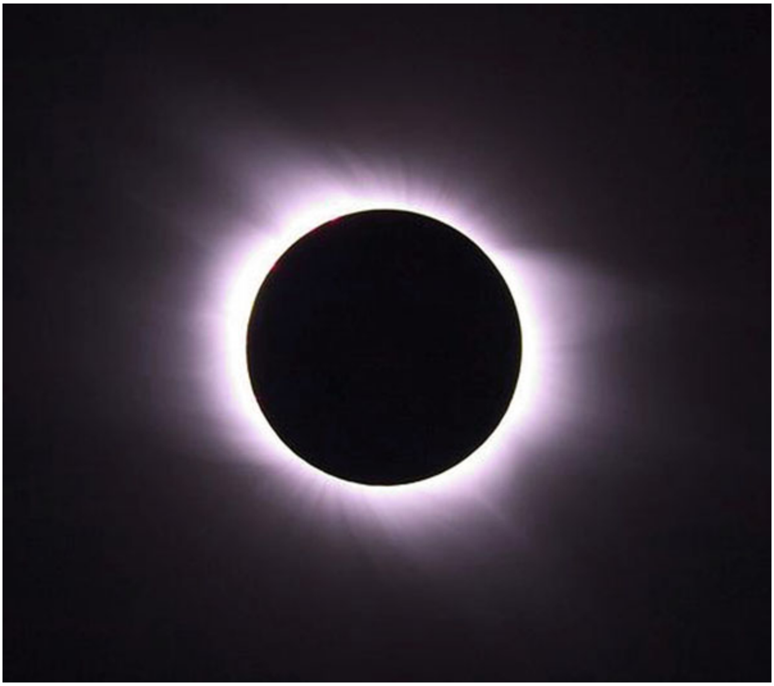

Fig. 2.4 The solar eclipse of August 1, 2008, at the point of totality, when the moon completely blocks out the body of the sun, revealing the corona (Credit: The Exploratorium, NASA)

and the observer. The coronagraph has enabled astronomers to study the outer area of the Sun, just one millionth of the brightness of the main photosphere.

What we are observing here is solar gas flowing into space. It was thought for a long time that the incredible temperatures of the corona and its corresponding Fraunhofer lines were evidence of a special chemical element. In fact, these lines show familiar terrestrial elements but under extraordinary conditions. The corona is expanding in every direction, creating a wind of charged particles. If you use a coronagraph, you will see streamers trapped by solar magnetism flow back towards the Sun in helmet loops while others spread into the darkness of space.

Where do they go? Observing the solar corona is a good place from which to glimpse the solar wind.

The existence of this wind is now so much part of our understanding of the Solar System that it is easy to forget how recent is its discovery. It is also a good example of how theory and observation interact, and sometimes don't, in science.

The earliest ideas that there was some sort of flowing solar force came from observing how comet tails always point away from the Sun. This led astronomers to conclude that something was pushing the tails to do this, perhaps sunlight itself.

The idea of solar wind emerged out of experiments conducted by the Norwegian Kristian Birkeland (1867–1917). Writing a report on the Norwegian polar expedition of 1902–3, he proposed that "aurora and magnetic perturbations should be regarded as rather moderate manifestations of an unknown cosmic agent of solar origin." Conflicting models of the way the solar corona might work were constructed later by Ludwig Biermann (1907–1986) and Sydney Chapman (1888–1970), Biermann proposing a stream of particles he called corpuscular radiation, and Chapman arguing for a corona that was static and not expanding. In 1958, Eugene Parker entered the fray, creating the phrase 'solar wind' to describe the relentless outward expansion of the Sun.

If the theory of the solar wind was right, could it be measured in practice? By 1958 both the United States and the USSR were sending satellites into space, but measuring the solar wind proved far from easy. Three Soviet satellites tried to feel the wind in 1959, and they did provide some data in support of Parker's theory. So did the Soviet Venus probe of 1961. Meanwhile the American *Explorer 12* satellite seemed to prove the negative during a 4-month mission in the same year. The next three U. S. satellites with experiments on them all failed. But the overheating, battered U. S. spacecraft *Mariner 2* ended the uncertainty in 1962. There was a solar wind, and it was blowing past *Mariner 2* in a steady gale.

It turned out to be a gale of two parts. One of the puzzling and fascinating results from the study was the discovery of the two phases of the solar wind, the fast and the slow. Like all the best experiments, then, *Mariner 2* presented answers and then asked the next set of questions.

Recent satellites have taught us more about the solar wind. The joint NASA-ESA *Ulysses* spacecraft, which ended operations in 2009, provided data from above the northern and southern poles of the Sun and studied variations in the solar wind during maximum and minimum periods of solar activity. NASA's ACE

(Advanced Composition Explorer) satellite is contentedly sampling and studying the solar wind and will continue doing so until 2024 if its fuel holds out. Such are the advances in our ability to measure the solar wind that it is now possible to get a daily reading of the solar wind on a personal computer.

The *Skylab* space station carried eight solar experiments, and X-ray images taken during the manned missions of 1973–1974 enabled a first prolonged view of the Sun's hot corona. Skylab's manned missions ended in 1974 and plans to revisit it were curtailed by the same Sun that the space station had been so assiduously studying. Predictions of solar weather had failed to predict a burst in the Sun's activity that had increased the drag on the spacecraft, pulling it out of position. It was this that led to the early demise of the first U. S. space station, brought down by the Sun.

In 2001, NASA launched a remarkable attempt not only to measure but also to bring back to Earth a sample of the solar wind. The *Genesis* spacecraft was the first sample-return mission since *Apollo* and spent 886 days collecting the wind's diffuse ions. The return capsule entered Earth's atmosphere on September 8, 2004, but a design error resulted in the parachute failing to deploy, and the precious cargo crashed into the Utah desert. Amazingly, it proved possible to rescue the solar wind collector from the debris.

From this and other evidence, it now seems that the oxygen and nitrogen isotopes in the solar wind are like those found in the atmosphere of Jupiter but unlike those common on Earth. We don't yet know what this really means. Studies of the solar wind, and our place within it, may yet reveal many secrets of the power and influence of the Sun.

Just how powerful is the Sun? All the planets are embedded in the solar wind, but it is of course stronger nearer the Sun than in the outer reaches of the Solar System. At Mercury, 0.39 AU from the Sun, the solar wind's density is 53 cm^{-3} and around Earth 7 cm^{-3}. By Jupiter, it has diminished to 0.2 cm^{-3}, and by distant Neptune, it amounts to just .0006 cm^{-3}. Beyond Neptune, the Sun's power tails off into an area called the heliopause, where the *Voyager* spacecraft are now at work.

The role of spacecraft in measuring the solar wind is only one part of the array of remote probes doing what we cannot do safely, staring at the Sun.

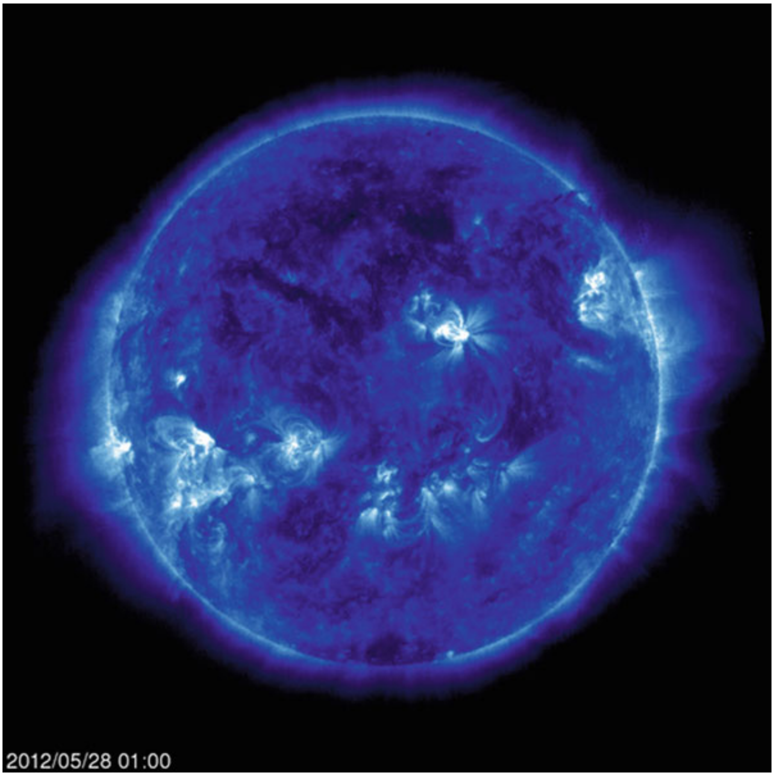

Fig. 2.5 This image was taken by NASA's SoHo mission on day of writing (Credit: NASA/ ESA)

Their data is readily available on the Internet, such that it is perfectly normal today to be informed of current solar conditions and download extraordinary images of solar activity. Websites for NASA's SoHo (Solar and Heliospheric Observatory) and SDO (Solar Dynamics Observatory) provide images of the Sun for each day, such as the one above, as well as movies and special reports on prominences and sunspots. These and other data mean that it's possible to check observations, particularly of sunspots, against the evidence of these immensely powerful instruments.

Sound and Glory

The images of the Sun captured by these spacecraft are awe-inspiring. But nothing binds science to wonder so closely as the Northern and Southern Lights. They reveal the solar wind.

Humans have been recording aurorae since the Babylonians made astronomical notes on baked clay tablets in the sixth century BCE, and they remain among the most beautiful revelations of how we are bound within the solar environment.

What causes the aurorae? As solar particles move into Earth's magnetosphere they travel to its day or night side along the magnetic field lines. When these magnetic field lines reconnect in an area known as the magnetotail, energy is released, and this sends the particles down onto Earth's poles, and sometimes even lower latitudes. As the particles bombard oxygen and nitrogen in the upper atmosphere, the atoms release photons of light that we see as the auroral colors.

The details of the science remain uncertain. In 2007, NASA launched the Themis mission to study the interaction between the solar wind and Earth's magnetosphere. The mission hopes to identify which of the several theories connecting solar storms with aurorae might be correct. At time of writing, Themis's mission has been extended. It could help us unlock the aurora's secrets. But it will never take away the wonder of the Sun's power at work.

It is also possible to listen to that power. Not only do some people claim to be able to hear the aurorae, but violins of the late seventeenth century, known for their superior quality, probably derive their sound from the power, or lack of power, in the Sun. It is thought that great Stradivarius instruments derive their timber from the particular strength and density of the wood out of which they were made. The trees from which the materials came grew during a period of exceptional solar quiescence at that time – known as the Maunder Minimum.

It seems likely that the unique conditions created by the Sun's half-century doze are the cause of some of the world's sweetest music.

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