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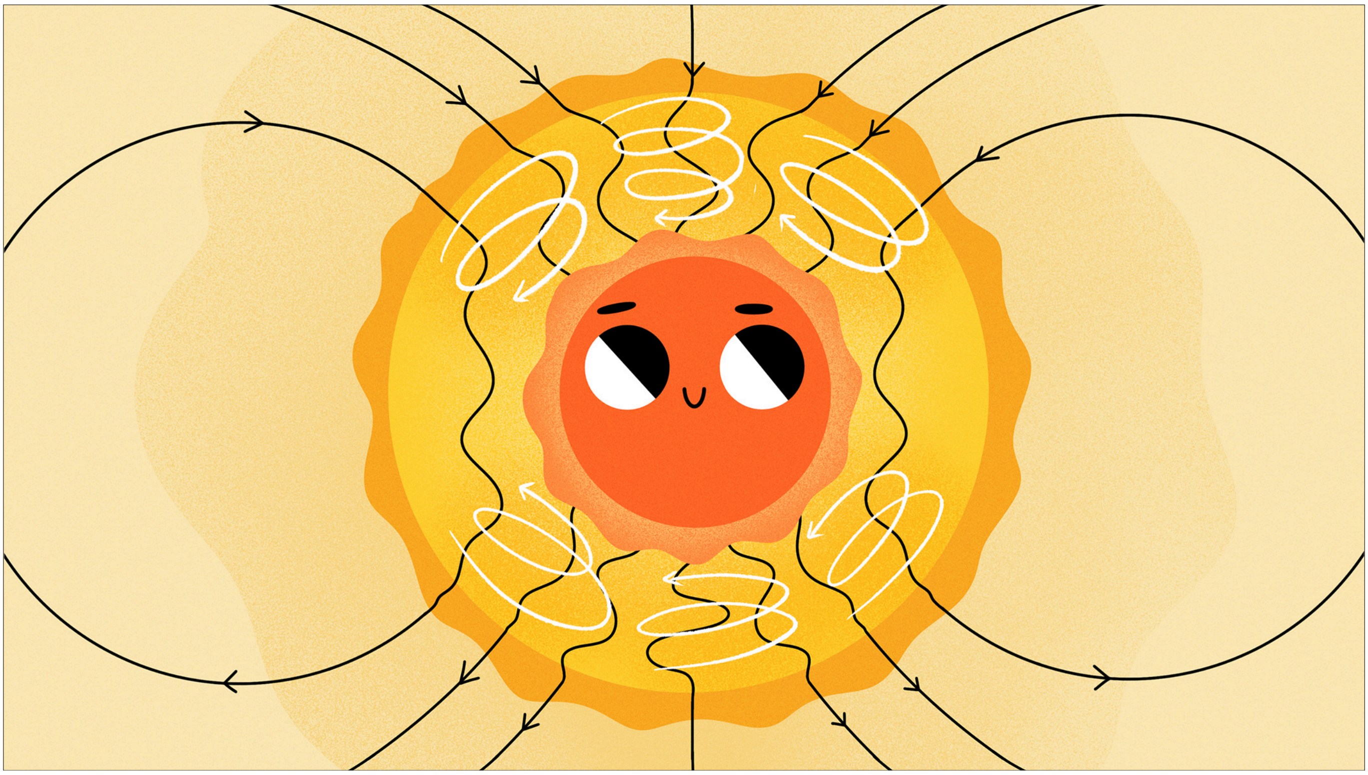

UNCOVERING THE SECRETS OF THE SUN'S MAGNETIC FIELD

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YOUNG REVIEWERS:

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AGE: 11

Humans have admired the Sun for as long as they have existed because life simply would not be possible without it. Today, we know that the Sun is not just a blazing ball of light but an extremely complex space laboratory in our cosmic neighborhood. In this article, you will read about the mystery of the Sun—how it acts as a gigantic magnet through a process called the solar dynamo. We will also describe the methods scientists use to understand this mystery.

MEET THE SUN AND ITS MAGNETIC FEATURES

The Sun is our very own star. It not only defines our days, seasons, and years but also extends its warmth to us, permitting the survival of all creatures on Earth. Without the Sun, our familiar, lush home would become an unrecognizable frozen wasteland enveloped in complete darkness. Because of its importance in our lives, the Sun has fascinated humans since ancient times, and it was once worshiped as a god by almost every civilization. While our ancestors could only peek at the Sun through the safety of clouds or fog, scientists today have revealed more details using special telescopes both on the ground and in outer space (Figures 1A, B).

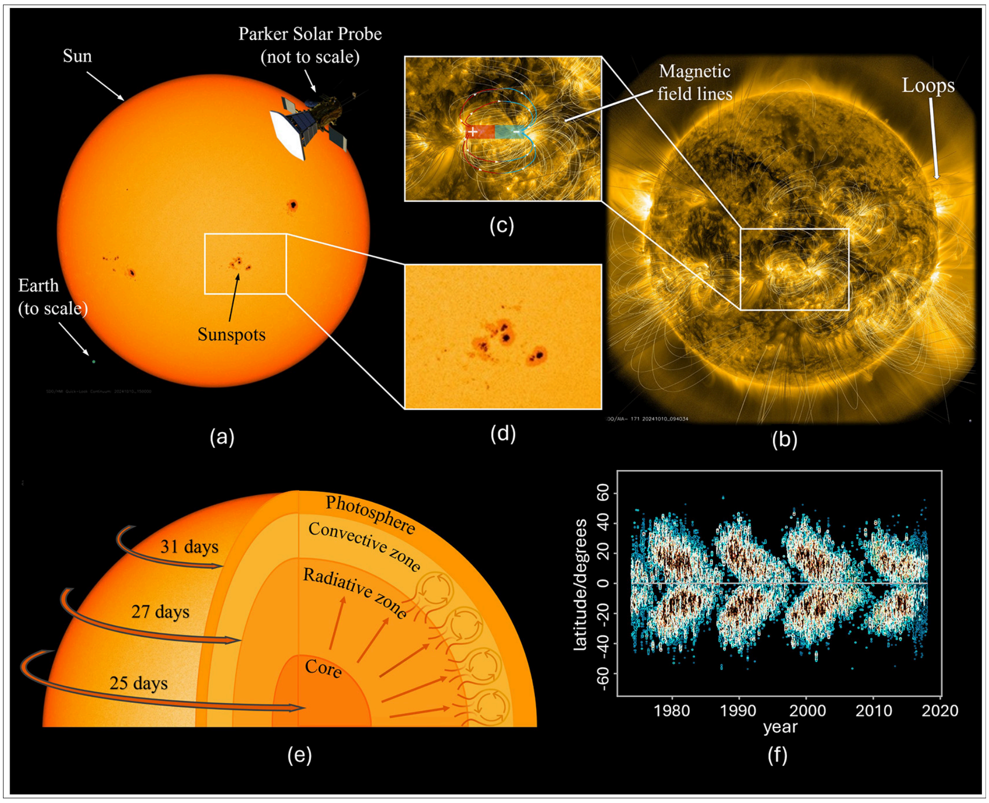

Figure 1

Figure 1

(A, B) Photos of the Sun on October 10, 2024, taken by the spacecraft Solar Dynamics Observatory [NASA/SDO]. **(A)** is in visible light and **(B)** is the same photo in ultraviolet. **(C, D)** Close-up views of a group of sunspots, where the white lines visualize invisible magnetic fields [NASA/SDO]. **(E)** The internal layers of the Sun with the different parts of the solar surface rotating at different speeds. **(F)** The butterfly diagram shows when (*X*-axis) and where (*Y*-axis) astronomers observe sunspots, each represented by a dot.

As we now know, the Sun is a massive ball of hot gas (or **plasma** to be precise) with a layered interior (Figure 1E). The powerhouse of the Sun is its core, where tiny parts of atoms called protons and neutrons collide and merge to generate immense heat, in a process called nuclear fusion. Then, over millions of years, heat slowly moves through the layer called the radiative zone. Once that heat reaches the next layer, the convection zone, it drives the gas in that layer to swirl and churn like boiling water. Above the boiling gas is the solar surface, known as the photosphere, which is what we can see with the naked eye—but you should never look at the Sun directly without eye protection!

PLASMA

An extremely hot gas with free-flowing positive and negative charges. It is usually regarded as the fourth state of matter in addition to solid, gas, and liquid.

You may wonder why there are dark patches (sunspots) in Figure 1A and bright loops in Figure 1B (these features are shown close-up in Figures 1C, D). Sunspots appear darker because they are colder regions of the solar surface. For centuries, astronomers have recorded when and where they see sunspots, and plotting their observations produces the butterfly diagram (Figure 1F). The flying "butterfly" shape shows us that sunspots appear and disappear every 11 years, a period known as the **solar cycle**. This curious behavior happens because the Sun

SOLAR CYCLE

An approximately 11-year change in the Sun's magnetic activities, measured in terms of variations in the number of observed sunspots.

is a gigantic magnet that "sprouts" smaller magnets—sunspots! Over one solar cycle, the magnetic activity increases and decreases, causing dramatic changes in the number of sunspots.

MAGNETIC FIELD

An invisible force field usually found near a magnet or an electric current.

The bright loops roughly indicate where the invisible solar **magnetic fields** are. Strong radiation is emitted when charged particles, such as protons and electrons, travel along these magnetic field loops. Occasionally, some loops "snap" and result in extremely powerful explosions called solar flares. These sudden bursts of energy can be very dangerous for satellites and power grids, while simultaneously painting the night sky with beautiful **auroras**. Books [1, 2] give more details.

AURORAS

A colorful light show in the sky which naturally occurs because of particles from the Sun striking our atmosphere and lighting up the sky.

HOW IS THE SUN'S MAGNETIC FIELD GENERATED?

The exact reason why solar magnetic activity rises and falls every 11 years remains largely a mystery. Despite our very limited access to what is beneath the solar surface, we know that such a strange, cyclic magnetic field is fundamentally different from magnetic fields that do not change with time, for example, the field produced by a bar magnet. This suggests that there must be some internal process responsible. But how is it possible to have a magnet that is continually and regularly changing?

The basic principle behind an ever-changing magnetic field that sustains itself, similar to that of the Sun, can be understood from a simple device called the Faraday disc dynamo. Here, the word "dynamo" means generator. The initial design by English scientist Michael Faraday (1791–1867) consisted of a metal disc placed within the magnetic field produced by a permanent magnet (Figure 2A). When the disc spins, it interacts with the magnetic field, and generates an electric current that starts to flow in the **circuit**. This effect is called Faraday's Law, which states that when a **conductor** (such as the metal disc) moves in a magnetic field, an electric current starts to flow within it.

CIRCUIT

A closed path or complete loop which electricity can flow through.

CONDUCTOR

A material which allows electricity to flow through it.

Now, let us divert the electric current in the circuit through a helical coil of wire, known as a solenoid (Figure 2B). Then Ampere's Law, named after the French physicist Andre'-Marie Ampe're (1775–1836), tells us that a current flowing in a conductor generates a second magnetic field in the center of the solenoid. As the disc continues to spin, the current generated within the circuit strengthens the magnetic field produced by the solenoid, which in turn leads to more current being produced.

Thus, the induced current and the secondary magnetic field reinforce each other, continually making each other stronger. The permanent magnet becomes unimportant and can be removed altogether. Eventually, the secondary magnetic field stops to grow because of

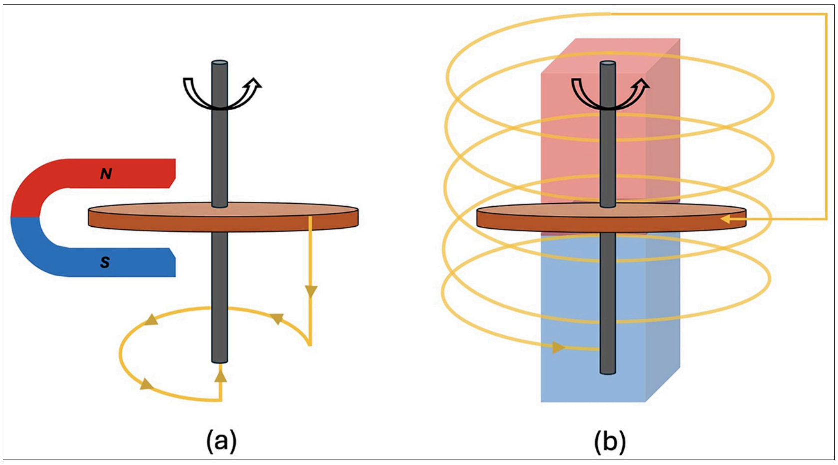

Figure 2

Figure 2

The Faraday disc dynamo. **(A)** Initially, a seed magnetic field stretches between the poles of a permanent magnet. **(B)** The induced current is channeled through a solenoid (yellow spiral) to produce a second magnetic field, which further strengthens the induced current and subsequently its own self!

sliding forces (friction) and electrical resistance but remains strong. Of course, other conditions need to be satisfied but they are less relevant. For example, all of this happens only when the disc rotates fast enough. The key takeaway from the setup is that a strong magnetic field can be generated and replenished from some weak starting "seed" (permanent magnet). This is discussed further in paper [3].

Scientists now believe that a similar process, called the solar dynamo, occurs in the convection zone. Instead of a rotating disc and a solenoid as in the Faraday disc dynamo, it is hot, electrically conducting gas that "boils" vigorously beneath the surface of the Sun that is responsible for converting electric current and magnetic fields back and forth. The existence of a solar dynamo could explain the mysterious 11-year changes in the number of sunspots.

DISCOVERING AND UNDERSTANDING THE SOLAR DYNAMO

SCIENTIFIC METHOD

A process used by scientists to understand natural phenomena, which includes making observations, asking questions, seeking answers through reasoning, and testing hypotheses.

The idea of the solar dynamo did not come out of the blue. Rather, it arose from the use of the **scientific method** (Figure 3) by generations of scientists. Driven by curiosity, we have been asking questions about natural phenomena since the dawn of civilization. Scientists propose possible explanations with logical reasoning and test their ideas against known observations or using intricate experiments. It is unusual to get the answer correct on the first few attempts, but this does not stop scientists from repeating the process after modifying their ideas as explained in book [4].

Returning to our case, the 11-year changes in the number of sunspots were intriguing to scientists, who wanted to investigate their causes. The mechanical example of the Faraday disc dynamo inspired scientists to make an educated guess that solar magnetic fields could

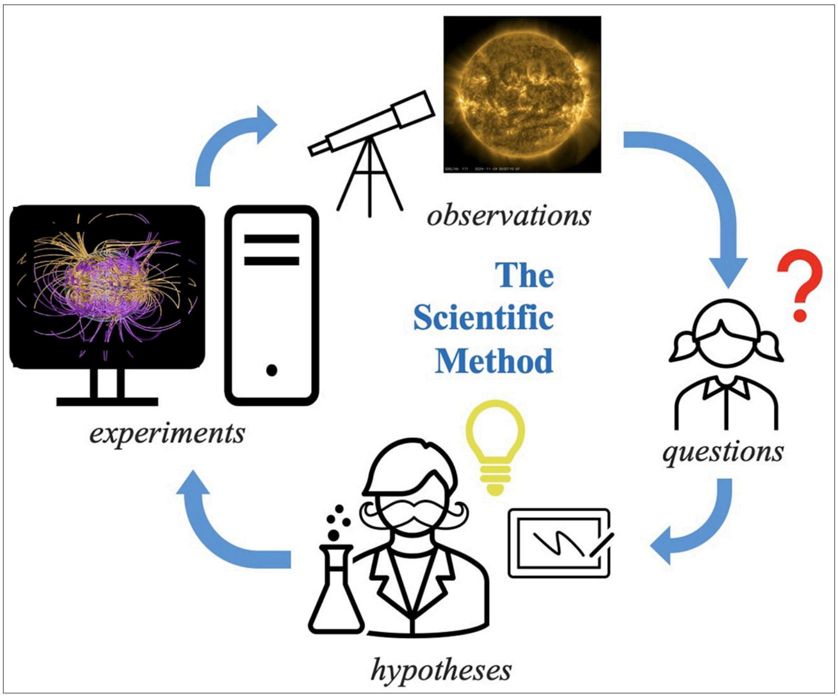

Figure 3

Figure 3

The scientific method was used to discover and understand the solar dynamo. [**(Top Panel)** NASA/SDO; **(Left Panel)** adapted from Silva et al. [5] under license CC-BY 4.0].

be generated in a similar way and replenished due to plasma motion. However, it is not easy to put such an idea to the test, since we cannot probe the interior of the Sun or run actual experiments on something as large or powerful.

When the idea of a solar dynamo was still in its infancy around the mid-twentieth century, scientists had little choice but to resort to pen-and-paper calculations for simplified or toy models of the solar dynamo. They quickly deduced that the boiling gas cannot conduct electricity without some resistance, but the gas must be at least somewhat conductive. They also found that magnetic fields would die out if the flow pattern of the gas is too symmetric, for example, if the flow looks the same when rotated around an axis. As more and more scenarios proved impossible, many scientists started to question if their attempts to understand the solar dynamo were a dead end.

NUMERICAL EXPERIMENTS

Also called a computer simulation; a process that uses a computer program to simulate a real-world phenomenon or a physical system according to certain rules or laws of nature.

The invention of computers gave scientists new hope since computers can perform calculations much faster than humans. After programming the laws of nature into computers, the movement of millions of particles can be simulated, just like a video game. This has allowed scientists to conduct **numerical experiments** for the solar dynamo on small silicon chips, which would not have been possible even in their wildest dreams before computers. If the results match what we see happening on the Sun, that is good evidence that the original idea of a solar dynamo is correct. With supercomputers that are millions of times more powerful than a personal laptop, we can nearly reproduce the entire 11-year solar cycle as it exists in real life.

While we have a rough idea of how the solar dynamo may work within the Sun, there are still many more phenomena that cannot be explained or reproduced, for example, the irregular rotation within the convection zone or the evolution of sunspots. Scientists are running numerical experiments with inputs similar to the actual solar values, using increasingly powerful computers and trendy machine learning techniques. Although no computer will ever be able to recreate a complete model, we are closer than ever to understanding the solar dynamo.

THE UNSOLVED MYSTERY—WHAT'S NEXT?

In the years 2024 and 2025, the Sun will be in its most active phase in the current 11-year cycle, with many sunspots to come and possibly more auroras to be seen. Of course, science will also advance during this period. Understanding the Sun and its magnetic fields better will not only protect us from harmful solar eruptions but will also enable us to comprehend how other stars in the vast universe might work. We hope that, in 11 more years when the Sun is active again, you may be one of the lead detectives on this decades-long mystery.

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REFERENCES

1. Vaquero, J. M., and Va'zquez, M. 2009. *The Sun Recorded through History*. New York, NY: Springer-Verlag.
2. Priest, E. 2014. *Magnetohydrodynamics of the Sun.* Cambridge: Cambridge University Press.
3. Bullard, E. 1955. The stability of a homopolar dynamo. *Math. Proc. Cambridge Philos. Soc.* 51:744–60.
4. Di Ventra, M. 2018. *The Scientific Method.* Oxford: Oxford University Press.
5. Silva, L., Gupta, P., MacTaggart, D., and Simitev, R. D. 2020. Effects of shell thickness on cross-helicity generation in convection-driven spherical dynamos. *Fluids* 5:245. doi: 10.3390/fluids5040245

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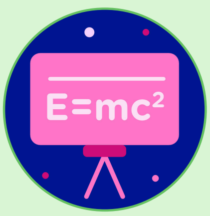

BAIRON, AGE: 11

I was born in California but moved to Florida when I was 2 months old. I was living happily in sunny Florida until I was 2 years old, when I moved to Texas with my parents and had been enjoying Texan's life until 5 years old. I then moved to Oregon to enjoy the mountains and rainy days. Quite a traveler I am!

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