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A Brief Introduction to the Sun

This book is about a special star, our star, a luminous disk which has always accompanied us, all living beings on this planet, humans, animals and plants. All phenomena, and processes on Earth are determined by the Sun's energy. The Sun gives us a sense of security through its continuous presence in the sky. Energy is needed for every force that causes things to move. All living organisms take in and release energy, and they do it continually. Energy delivered to us by the Sun, so necessary for life on Earth, is produced by nuclear fusion in its center.

Has the Sun always been in the sky? And will it be there forever to give us life through its energy? Modern astrophysicists say: Certainly not! The Sun too will die in some finite time.

During our own finite time on Earth, we humans have had different ways of thinking about the Sun, from prehistoric people who honored and worshipped it as a god to our technological times, in which it is viewed as one among billions of others in the Universe, but no less important for that.

I remember, as a child, my first serious personal encounter with the Sun, which was inspired by a movie "Miracle in Milan," made in 1951 and directed by Vittorio De Sica. For reasons of age, I did not see it then. I saw it in 1960 on our first black and white TV. The film tells of a group of desperately poor people living on the outskirts of a big city, Milan, a city that is always gray and cold—at least, it was in this story. These people possessed nothing but the pleasure of awaiting the Sun's rays to warm them up in the morning. Indeed, the scene in the movie which impressed me so much at my young age was the vision of a group of people illuminated by a single sunray. They were so happy to receive the precious gift of warmth.

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At the end of the movie, as in the fairy tales so much loved by children, these people are seen flying joyfully toward the Sun to end their miserable lives by reaching a better one somewhere else. There it was—a miracle! At least that was my interpretation as a child. I imagined a generous God giving pleasure to those poor individuals who had nothing else in their lives but the gift of the Sun's warmth. The movie was not only about the Sun's rays on a sad gray day. It was a fairytale set in times of difficult and dramatic social problems: the world post-World War Two! Through my child's eyes, I saw the Sun's rays as a divine intervention sent to help a needy population.

Our ancestors may have had the same feelings about the Sun, and therefore worshipped it as a god for this reason. Now, as an adult, my fascination for our star is still present in my mind. I like the idea of taking a voyage through time, encountering ancient cultures and their myths and legends about our star, and returning to our modern-day astrophysical understanding, which needless to say I find just as fascinating as that ancient folklore.

This book is a biography. Such things are generally written to glorify or denigrate important people, usually long gone, although not necessarily. They could still be alive, but they are always of great importance for their goodness, or their wickedness. Well known poets, writers, artists, scientists, politicians, but all humans. This biography is different. It's a glorification, not of a very important human, but of a very important celestial object: the Sun (Fig. 1.1).

1.1 The Sun in Ancient and Recent Human History

Our star has been a central object of religion, legends, and myths from time immemorial, but eventually described by the scientific concepts of astronomy. Solar worship, solar rituals, and solar deities featured in common beliefs across the continents, even when separated by the immensity of the oceans. In ancient times, from Europe to Asia, to the Americas, to China and Australia, humans worshipped our Sun as a life-giver, as a god. The Sun has been a key protagonist since our ancestors appeared on this planet, it's fascination and mystery inspiring myths, legends, superstitions, and beautiful art.

Thanks to early visual art, we know about some of the rituals and beliefs of ancient populations around the world. Artistic representations of the Sun, through paintings, sculptures, architecture, and even music, have given us a wealth of information from before written language was invented. Music in particular has been an innate form of artistic expression since primordial times. It is known to have existed around the world for at least 55000 years,

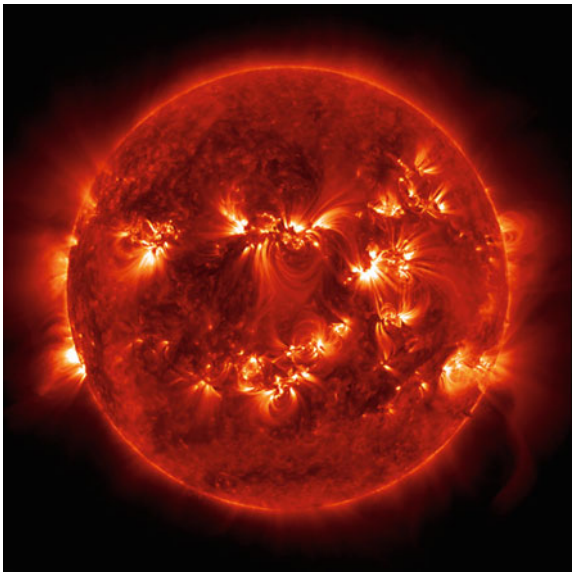

Fig. 1.1 This is a real image of the Sun taken by the science team at NASA. The Sun has been imagined in different ways across the centuries, as a powerful entity crossing the sky on a golden chariot, sailing on boats, as a beautiful young man or a cruel bloodthirsty being, and many other things besides. But here we see the true face of our Sun, beautiful, powerful, and somehow spooky. Courtesy of NASA/SDO and AIA, EVE, and HMI science team

but, in contrast to visual art, without any written form, it was not possible to record it, so we cannot know what it was really like. Archaeologists have found traces of musical texts on clay tablets, written in a cuneiform alphabet over 3000 years ago. The lyrics of ancient songs were mostly religious, but there is one, entitled "Sumer is icumen in" (Summer is a coming in) written in the thirteenth century by an unknown English musician, in which the summer sun was welcomed. It is the oldest music with lyrics recorded in Medieval England, and as far as we know, anywhere.

Coming back to our own times, on the contrary, songs celebrating the Sun are very present, and can be heard everywhere, on the radio and television, in bars, on city streets, in theaters, yes, just about anywhere. To mention some of the most popular ones, think of "O sole mio" sung by Enrico Caruso, written in the late 1800s, recent ones like the Beatles' "Here comes the sun", "Walkin' on the Sun" by Smash Mouth, "Ain't no sunshine" by Bill Withers, "Walking on sunshine" by Katrina and the Waves, "Pocketful of sunshine" by Natasha Bedingfield, and "Let the sunshine in" by the Fifth Dimension. All of these belong to the twentieth century, but I am sure there have been many more songs about the Sun in different countries and in different languages.

The Sun has also been a protagonist in poetry, literature, and art, through the centuries right up to our own time. Think of Dante's lyrics in the "Divine Comedy", Charles Baudelaire, Emily Dickinson, Ugo Foscolo, Pablo Neruda, Alessandro Manzoni, Mother Teresa of Calcutta, the list is long. Then there are visual artists like Vincent van Gogh, with his famous sunflowers, painted in the best bright yellow colors ever imagined, and many more artists who have celebrated the Sun throughout history. And of course, there are modern physicists, who celebrate the Sun through science.

Myths, legends, superstitions, and esoteric beliefs about our star have been widespread in all ancient societies, and some of them have survived right up to our own technological times. Astrology, for example, has been practised around the world since the observation of the sky by the Mesopotamian astronomers. Considered as a science for centuries, it is known nowadays to be just a myth or superstition, even though it is still highly appreciated by many contemporary humans. In the astrological chart, the Sun symbolizes our personality, the real aspects of us as a person, so it is the most relevant celestial body for a personal astrological chart.

Tarot card reading is another ancient belief, practised since the fifteenth century. It started in Italy and eventually spread all over Europe, where it is still practised by many even now. It consists of a pack of 78 playing cards used to predict the future. Every card carries an image with a symbol and a story. It is rather like a kind of oracle. In fact, the interpretation of the card depends on the person who reads it. The one picturing the Sun is a particularly important one, with a symbol that predicts happiness, contentment, vitality, self-confidence, and success. The best card of all! At least in my opinion. But to expert tarot card readers, the most important card is the one represented by "the fool", and they may well be right, considering how humanity often behaves. The art of reading tarot cards, like the art of reading horoscopes in astrology, is still appreciated and practised around the world today.

Besides these esoteric beliefs, throughout history there have been remarkable poets who have glorified the Sun through their beautiful poetry. "The Divine Comedy," for example, was written by the well-known Florentine poet Dante Alighieri in the thirteenth century. In the "Paradiso: Canto 33" he alludes to the importance of the Sun in these words "L'Amor che move il sole e l'altre stelle" (love that moves the Sun and other stars). What this means is that spiritual love (God) moves first the Sun and then the other stars in the heavens. The Sun is viewed, through Dante's words, as a glorious and divine central protagonist in the sky. Spiritual love (God) created the Sun and gave it the power to move stars in the heavens. It's a poetic version of the Sun's

birth. Considering that "The Divine Comedy" was written in the thirteenth century, and given the state of scientific knowledge at the time, which was based on a geocentric model, the Sun would not have had the power to move all the stars. But this is poetry!

Today, modern astrophysicists tell us a different story about the Sun's birth. We know now that our star was probably born 4.6 billion years ago. It was not spiritual love (God) that gave birth to the Sun. Its birth was triggered by the gravitational collapse of matter from a large dust cloud. At the present time, the Sun is about halfway through its life, and it has not changed much during the last four billion years or so. Astrophysicists think that it could very likely remain stable for another five to seven billion years. By becoming very hot and dense, after a very, very long time from our human point of view, nuclear fusion began to occur in its interior and is still going on today. However, when the fusion in its core has gone to completion, the Sun will change drastically, both internally and externally, and it will eventually die.

Melissa Pesce-Rollins, PhD Staff Research scientist at INFN in Pisa, explains how nuclear fusion works in the Sun:

> The Sun is powered by thermal-nuclear fusion. This is the process where protons (or a single hydrogen atom) are fused together to form helium, and it occurs in the deepest part of the Sun called the core. In order to form a helium atom, four hydrogen atoms must fuse together and the small difference in mass between these two is converted into energy.
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> This energy release can be explained by Einstein's famous mass–energy equivalence E=mc 2 and it is what keeps the Sun hot and bright. Thermonuclear fusion can only occur in very hostile conditions and is very difficult to mimic on Earth, but in the core of the Sun where the atmospheric pressure is over 200 times that of the Earth, the density is 150 times that of water and the temperature is 150 000 000 degrees Celsius, this process runs as smoothly as a windmill on a windy day.

It's an impressive process, but it is not only relevant to the Sun. All stars are born and live by this process. Perhaps, not a very poetic birth, but nevertheless stunning, impressive, and explosive, the glorious advent of our star in the Universe.

Following this description of the Sun's birth, a common question is, what exactly is our Sun made of? We know that it's a star, and generically speaking, it is a giant ionized globe, made up of atoms which have lost almost all their electrons. The Sun is a big ball of gas and plasma. Of course, the physical model of the Sun is very complex, but experimental physicist Melissa Pesce-Rollins explained things like this to simplify the description.

The Sun has a radius of about 700,000 km and a mass of 333,000 times the mass of the Earth. This is big, but in the Universe, there are many stars that are much larger than our own. As just mentioned, it comprises a combination of gases in the form of a plasma, that is, something similar to a gas, but in which most of the atoms have been ionized. Three quarters of its mass is hydrogen, which fuses together to form helium. This is nuclear fusion, as Melissa Pesce-Rollins described it above. A very small percentage of what remains is made up of other, heavier elements, such as iron, nickel, sulfur, neon, magnesium, calcium, and chromium. The Sun turns on its own axis, and it orbits around the center of the Milky Way, taking something between 225 million years and 250 million years to complete its orbit.

It's difficult to imagine such great distances and the very long time our star takes to orbit around what is actually only a very small part of the Universe. Indeed, our star is only one among millions and millions of others existing in the cosmos!

We see it in the sky as being a bright yellow color, and artists through the centuries have always painted it as a brilliant golden star. However, its real color is white, which contains all the colors of the visible spectrum. This means that the Sun is a combination of all colors mixed together to make it look white. And now, through observations from the International Space Station, it has been confirmed that the real color of the Sun is in effect white. Viewed from space, the Earth's atmosphere is no longer in the way to scatter light from it, and without this interference, we can see the full visible spectrum in its bright white color.

Astronomers call our star a "yellow dwarf" because it produces light in the yellow–green region of the electromagnetic spectrum. The latter consists of waves, most of which are invisible to us. Gamma rays, X rays, and ultraviolet rays (UV) are high frequency waves emitted by the Sun. Most of the UV waves are absorbed by the Earth's atmosphere, while the less harmful UV rays, which manage to get through the atmosphere, are the ones that cause sunburn. The Sun also emits infrared radiation, which is the energy we perceive as heat on Earth. Between the infrared and UV radiation, there is the visible part of the electromagnetic spectrum, the part we can detect with our eyes, which allows us to see all the colors around us.

The effects of the Sun on all living beings, both plants and animals, have been known and understood since prehistoric times. We can find out what our ancestors knew about Nature through primitive archaeological artifacts and cave paintings. Observation of the luminous disk, it's appearance and disappearance, and the fact of its returning again and again on the horizon, may have caused them to regard our Sun as a powerful god. And in a way, it

was. We can easily imagine our ancestors, observing the change in light and darkness from day to night, inventing myths to explain the cycle of our star in the sky. Eventually, this primitive belief evolved into more constructive and organized thoughts.