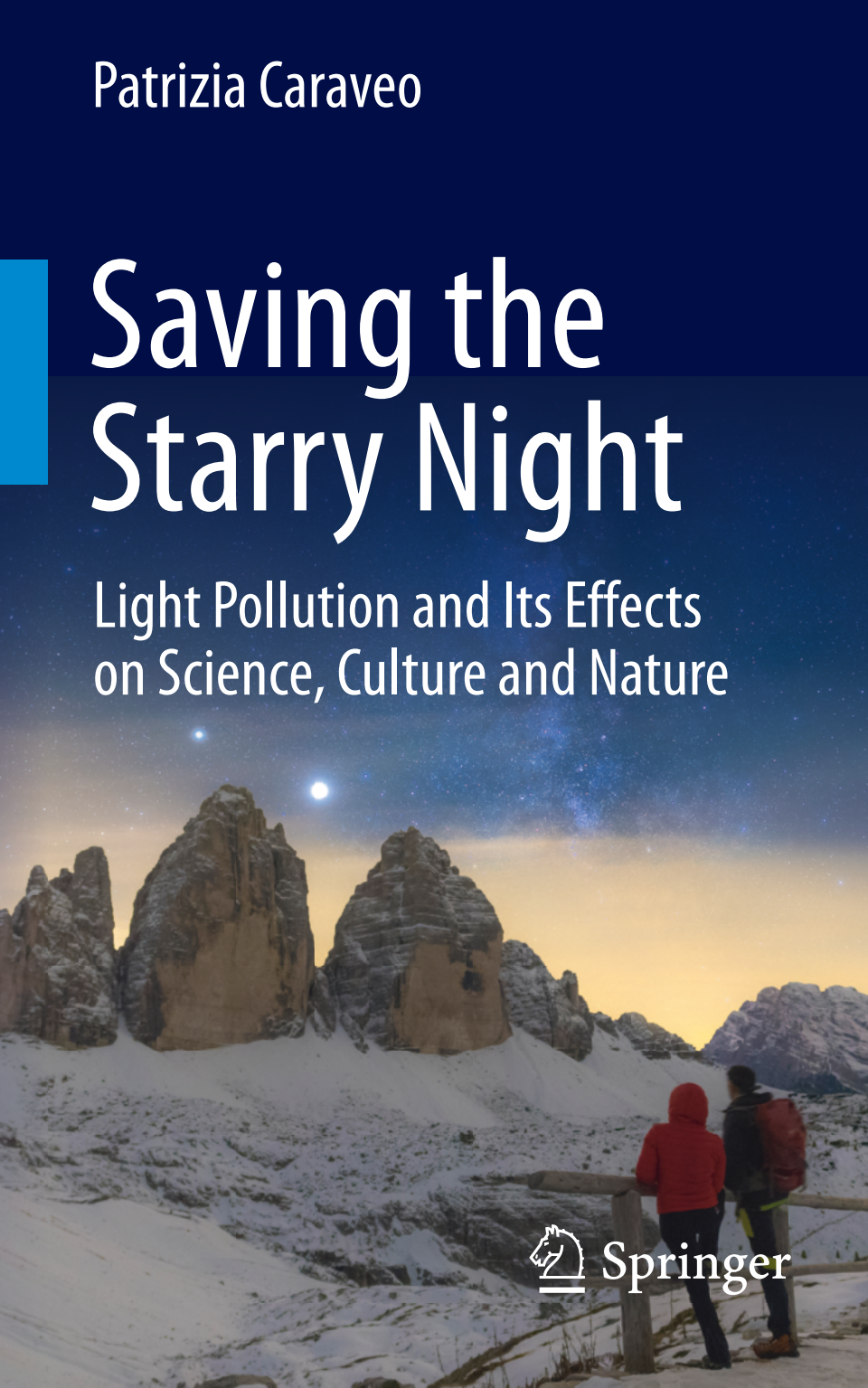
Patrizia Caraveo

Saving the Starry Night

Light Pollution and Its Effects on Science, Culture and Nature



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Light Pollution and Its Effects on Science, Culture and Nature

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Patrizia Caraveo
National Institute for Astrophysics
Milan, Italy

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Cover image credit: Astrophotographer Giorgia Hofer and partner admire Jupiter and Saturn shining above the Tre Cime di Lavaredo, an iconic landmark on the Italian Dolomites. The picture was taken at sunset at the beginning of October 2020, when the two planets were moving towards their Great Conjunction which happened in mid December (copyright Giorgia Hofer)

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To Giulia and her daddy
Great satellite hunters

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The Sky as Cultural Heritage

I am an astronomer, and consider myself to be a very lucky person. Studying the sky is the second oldest job in the world, and certainly the most fascinating.

The astronomers of the past were marketing geniuses, because they managed to persuade kings and emperors that the future was written in the sky. They were so convincing that no ruler would think of making any decision without first hearing the opinion of the court astronomer. Now, we know that these were fantasies: the future is not written in the sky, which, on the contrary, holds memory of our cosmic past. In fact, with the exception of hydrogen, all of the elements of which we and everything around us are made were produced by the stars. We are stardust and, in my opinion, this explains why, since the dawn of time, humankind has been deeply fascinated by the sky.

It is no coincidence that the words 'cosmology' and 'cosmetics' have the same root. Cosmos means beauty. All

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we have to do is look up and the sky is at our disposal, without the need for a reservation or a ticket. The great celestial beauty is there waiting for us, ready to amaze us with its special effects, as happened in the second half of 2020 with Jupiter and Saturn approaching their spectacular **great conjunction** (Fig. 1.1).

Stephen Hawking used to say "Remember to look up at the stars and not down at your feet. Try to make sense of what you see and wonder about what makes the universe exist".

I really think we should take his advice!

In fact, there are many ways to enjoy the beauty of the starry sky. We can admire it and let our imagination run free to populate it with the myths of our culture, or, while continuing to admire it, we can study it so as to understand the laws that govern the Universe.

Since fantastic-mythological use has been with human kind since its origins, let's try to compare the celestial stories, examining the meaning of the same constellations as seen by different cultures. Depending on the place and the epoch we consider, the stars tell stories that are sometimes similar, sometimes very different, involving loves and betrayals, escapes and reunions, battles and hunts, heinous crimes and sublime actions. Orion, with the three beautiful stars in its belt, is an example of the multitude of possible interpretations. Aside from the belt of the womanizing hunter who culminates in autumn-winter, during the hunting season, the three stars represent the wrist of a hand for the Lakota Indians, a canoe with three fishermen for the Australian aborigines, the primordial turtle for the Mayas, and the firelighters for the Aztecs. Not a bad example of varied storytelling, and I left out the more gory and less edifying tales that might induce the supporters of political correctness to change the name of the constellation that, despite having its origins in Greek mythology,

Fig. 1.1 Spectacular view of Jupiter (the brightest source) and Saturn (to the left) above the Three Peaks of Lavaredo in the Italian Dolomites. Astrophotographer Giorgia Hofer and her partner are also in the picture taken at sunset at the beginning of October 2020. This image has been chosen to be the APOD (Astronomy Picture of the day) of Oct.20, 2020

is, in fact, an example of celestial globalization, since all but one of its stars have Arabic names (the exception being Bellatrix, a small concession to Latin).

Let's move on to the Pleiades, an example of "cosmic" coincidence, since the myth of the seven fleeing sisters, pursued by a hunter, is found in very distant cultures that never had occasion to come into contact before the last few centuries. In Greek culture, they are the daughters of Atlas who, pursued by Orion, were transformed into stars, but for the Iroquois, they are children who, mistreated by their parents, fled into the sky. For the Aztecs, they were at the centre of a terrible (and very complicated) fratricidal story for which the population must have had a particular

predilection, because the largest temple in Mexico City was dedicated to the exterminating god. In other words, they represent a myriad of legends, generally with strong hues that often have a link to real life, as in Indonesia and Africa, where the appearance of the Pleiades was the signal to begin ploughing, while in the Andes, they were used to predict future rainfall, a method that may involve a grain of truth, since, in the presence of El Nino, the visibility of the stars is blurred.

Australians' stories are focussed on the Milky Way, which, in the Aboriginal tradition, is the path of the souls of the dead, but the clouds of dust that dominate it near the galactic centre are a symbol of life, because they are in the shape of an emu caught in the moment of hatching. This is a celestial signal: in spring, when the centre of the Galaxy becomes visible in Australia, it is time to start collecting emu eggs, so important for the survival of tribes that live in territories with very few resources.

Countless nights of patient observations with the naked eye, together with amazing intuitions, allowed our ancestors to understand that celestial bodies can be divided into two classes: the stars and the planets, true celestial wanderers whose continuous movements follow clear periodicities that can be used to anticipate celestial phenomena. The ability to make predictions takes us into the field of astronomy, the oldest science and the only one to have a muse: Urania.

Apart from being fascinating, astronomy has been a useful science for millennia. The Sun, Moon and stars have served as humankind's clock and calendar, and have also pointed travellers in the right direction. Basic astronomical knowledge was fundamental to everyday life, and people were very familiar with the heavens. Considering the centrality of Sun worship in ancient megalithic civilizations, astronomer Fred Hoyle, in 1966, was the first to propose

that the impressive Stonehenge circle was an elaborate solar observatory capable of predicting eclipses.

Archaeologists have learned their lesson, and now always think of astronomy when they come across large constructions. Indeed, all civilizations have built solar observatories to follow the path of the rising point the Sun that, every semester, moves between two extremes, known as the summer and winter solstices.

The most recent discovery refers to a settlement at Aguada Felix in the Tabasco region of Mexico, where, using the return signal of a laser mounted on an aircraft, the presence of a large platform, 1400 m long, 400 wide and 10 m high, was revealed under a thick blanket of vegetation. Close to it, just in the middle of the long side, there is an observatory pyramid. Archaeologists call such configurations E structures, because they are oriented towards the EAST in such a way that, from the observatory pyramid, during the solstices, you can see the Sun rising at both ends of the imposing platform, made of earth and clay; the one at Aguada Felix is certainly the largest of the many E structures mapped by archaeologists in the region. What is most striking is the age of the platform, dating back to 1000 BC. It was clearly built prior to the settlement, as if to say that the ceremonial buildings were the starting point for the Mayan cities.

Even the great festivals that marked the passing of time in ancient pagane cultures (and that, in many cases, have survived to our days) have always had an explicit astronomical reference: we say farewell to the Sun, hoping that it will come back, then we celebrate its return, grateful that it keeps the promise of a new season of abundant harvests.

Teaching of astronomy was one of the pillars of medieval culture, in which astronomy, together with mathematics, geometry and music, was part of the arts of the

quadrivium, a fundamental stage in the education of Middle Age few scholars. In fact, the use of astronomical references was very common in the writings of the time. In the Italian cultural panorama, the work that best describes the close relationship between humans and the heavens is undoubtedly *The Divine Comedy*, a poetic journey that unfolds across Hell, Purgatory and Paradise. Written seven centuries ago by Dante Alighieri, *The Divine Comedy* is rich in astronomical references, which are used to indicate the time of day, the season of the year, and the direction to follow, showing that the sky was the reference system upon which everyone relied.

Not that the motion of the planets was always easy to explain. Mars, for example, occasionally changes the direction of its motion and turns back. Understanding the retrograde motions of the planets is anything but easy, especially if we assume that we, the observers of the sky, are at the centre of everything. This is called anthropocentrism, and it hides deep down in all of us. Whether we want it or not, we continue to think that we are at the centre of the system, even if this position complicates the geometric vision of the celestial spheres.

The Scientific Revolution Starts with Astronomy

In order to explain how the planets revolve around us in such a complicated way, astronomers built a wonderful mathematical model in which a planet describes a circle the centre of which moves along another circle that is centred on us. This is what we call the Ptolemaic model, and it held sway for over a thousand years until Copernicus made a portentous conceptual leap by managing to

simplify the model of planetary motion. However, this simplification came at a price: the centre of the planets' motion was no longer us, but rather our star. Copernicus turned the tables and proposed the heliocentric system, which is what we studied in school. Around the Sun rotate, in order, Mercury, Venus, the Earth, Mars, Jupiter and Saturn, that is, all the planets visible to the naked eye. The Copernican system is simpler and more elegant than the Ptolemaic one, but it has some collateral problems of a political-religious nature. The Ptolemaic, earth-centric view was apparently in agreement with the biblical narrative, and any change in astronomical interpretation necessarily had religious implications. Copernicus, who was a canon in Frombork, Poland, had invested decades of his life writing De Rivolutionibus Orbium Coelestium (where the word "revolutions" refers to the orbits of the celestial bodies that revolve around the Sun), a book containing his new view of the cosmos. Apparently, Copernicus was not anxious to publish the treatise, which saw the light of day in 1453, thanks to the insistence of his disciple Rheticus, when the author was nearing his end. Legend has it that Copernicus saw a copy of the book on his deathbed. Although it expounds a vision contrary to orthodoxy, the text did not arouse the interest of the Inquisition. Perhaps the difficulty of the treatment combined with a sibylline preface (not by Copernicus) shielded him. To transform a new mathematical model describing the orbits of the planets into a cultural revolution, it would take the technological leap of Galileo Galilei, who, in 1609, built his first optical instrument.

Galileo had adapted the "device for observing at a distance" invented by the Dutch spectacle-maker Hans Lipperhey, who, sensing its potential, had tried in vain to patent his brilliant idea in 1608. The request was refused

because the commission doubted that it would be possible to keep the combination of lenses at the base of the device a secret. In fact, the news began to spread throughout Europe, eventually reaching Galileo, a professor in Padua, who realized that he had a trump card in Murano glass. While, in Europe, they were combining spectacle lenses, he could use bigger (and better) lenses and obtain an instrument of superior performance. When, in August 1609, it reached eight magnifications, he convinced the Doge and the dignitaries to climb up to St. Mark's bell tower to see what the "cannocchiale" (a word he invented by combining 'cannone' ('tube')- with 'occhiale' ('glasses')) could mean for a maritime power like Venice. The Doge immediately understood the importance of the instrument and confirmed Galileo's chair for life, also granting him a significant increase in salary.

Galileo continued to improve his device until it reached 20–30 magnifications: a ridiculous number by today's standards, but, at the time, it was unrivalled. No one in Europe had anything like it.

He himself, speaking of his instrument, says that it was

> ..so excellent, that the things seen by means of it appear almost a thousand times larger and more than thirty times closer than if they were looked at with the natural faculty alone.

In the autumn of 1609, after meeting with the Doge, Galileo pointed his instrument at the sky and revolutionized astronomy.

He described these extraordinary observations in a booklet entitled Sidereus Nuncius, published in Venice in 1610. Despite the ambivalence of the Latin word 'nuncius', which means both message and messenger, Galileo does not pose as a celestial messenger; he is rather

conveying the message of the stars that, thanks to the help of the new instrument, he was able to decode.

Unlike Copernicus' book, Sidereus Nuncius is written in a simple and very clear way, with an excellent set of illustrations. It does not describe models, but rather observations that can be easily verified by anyone equipped with a similar instrument. However, the implications are truly revolutionary. While the mountains on the Moon contradict the Aristotelian theory of the spherical perfection of celestial bodies, the discovery of the Medicean planets, orbiting Jupiter, undermines, from its very foundations, the idea that all celestial bodies must rotate around the Earth, the only centre of the Ptolemaic system.

And that was just the beginning: in rapid succession, Galileo observed the spots on the surface of the Sun and the phases of Venus that represent the proof of the correctness of the Copernican theory, because only a planet moving *within* the orbit of the Earth around the Sun can have the phases.

Supporting Copernicus, the message of the stars put an end to the geocentric theory, causing serious collateral damage to Galileo, who had to face the Inquisition. However, nothing (and nobody) could stop the Copernican revolution: the Earth was no longer at the centre of the Universe and was destined to become a smaller and smaller entity in a cosmos that, thanks to new and more powerful instruments, was getting bigger and bigger. As time went by, the solar system became more populated, with satellites around Jupiter and Saturn, periodic comets that describe long elliptical orbits, new planets. Thanks to spectroscopy, the strengths of physics, astronomy and technology joined hand in hand to provide a powerful method for understanding what stars are made of, starting with our Sun. While trying to map the geometry of our Milky Way, astronomers had to surrender to