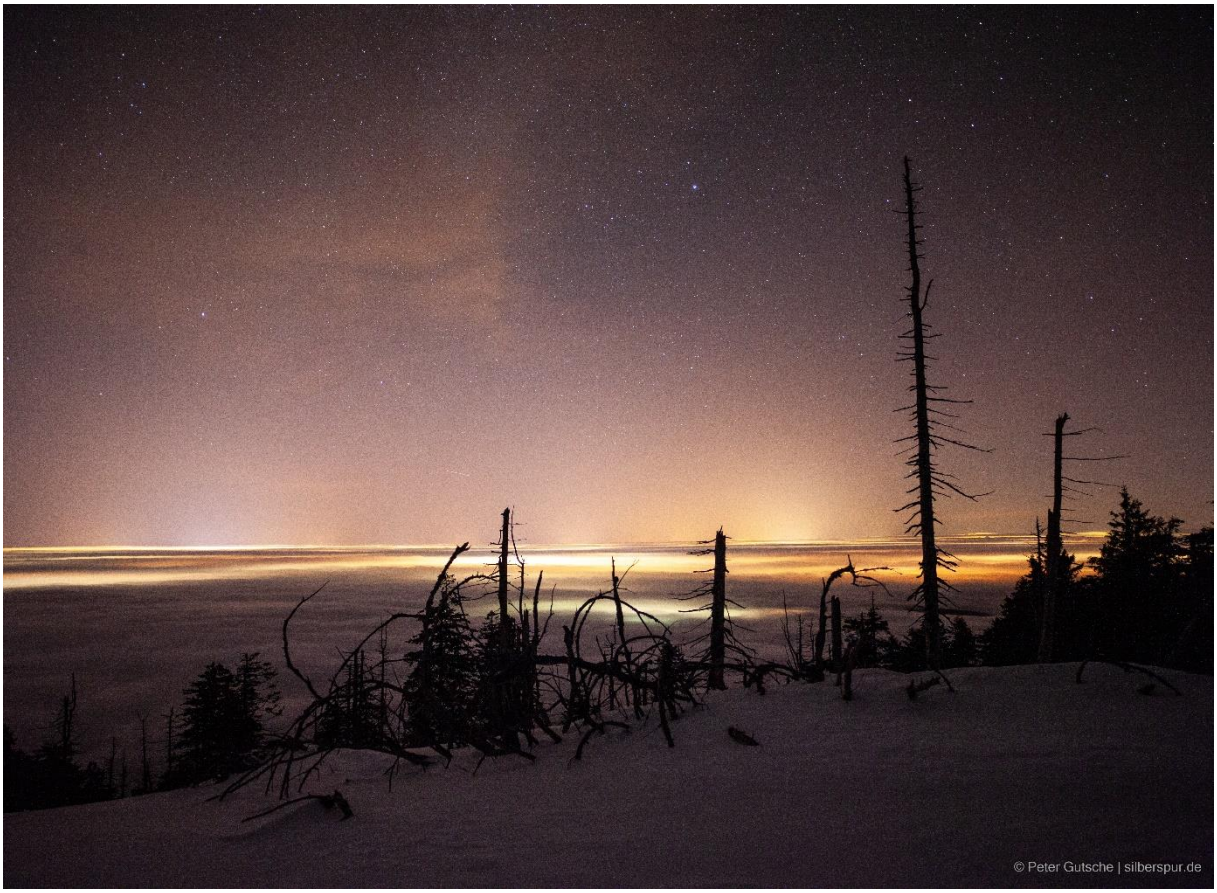
Why It won't be dark at night anymore (soon)

„Before we invented civilization our ancestors lived mainly in the open out under the sky. Before we devised artificial lights and atmospheric pollution and modern forms of nocturnal entertainment we watched the stars. There were practical calendar reasons of course but there was more to it than that. Even today the most jaded city dweller can be unexpectedly moved upon encountering a clear night sky studded with thousands of twinkling stars. When it happens to me after all these years it still takes my breath away.

In every culture, the sky and the religious impulse are intertwined. I lie back in an open field and the sky surrounds me. I'm overpowered by its scale. It's so vast and so far away that my own insignificance becomes palpable. But I don't feel rejected by the sky. I'm a part of it – tiny, to be sure, but everything is tiny compared to that overwhelming immensity. And when I concentrate on the stars, the planets, and their motions, I have an irresistible sense of machinery, clockwork, elegant precision working on a scale that, however lofty our aspirations, dwarfs and humbles us."

Carl Sagan[1]

The experience of a starry sky is one that humans have shared for millennia[2]. What impact would it have if the appearance of the naturally dark night sky – with its seemingly countless stars visible to the naked eye and the bright band of the Milky Way – were to be impaired? What happens to us humans if this experience is irretrievably lost for a large part of the Earth's inhabitants? What then happens to parts of the animal and plant world?



Lights under a sea of fog, seen from Hornisgrinde in the Black Forest; in high resolution: https://www.silberspur.de/topics/artificial-light-at-night/hornisgrinde-fog.jpg

In this article[3], I address a development that carries exactly this risk. I talk about the topic „artificial light at night“ (ALAM), also referred to as „light pollution“[4].

As I have been doing landscape photography during the dark hours for years, you will find a series of my own photographs for illustration[5]. As a „bonus track”, you will find a link to a high-resolution version of each photo.

Why is it dark at night?

This question may seem trivial, but it is not. Answering it requires a brief excursion into science. For those interested, there is a short article on this topic:

https://www.silberspur.de/articles/why-it-is-dark-at-night.pdf

Short answer: The universe is not infinitely old, nor is its observable region infinitely large. This ensures that the night sky appears dark to us on Earth. However, on clear nights, you can see thousands of stars and the glowing band of the Milky Way against this dark background. In the observable universe, there are hundreds of billions of star systems, galaxies, each containing hundreds of billions of stars. The stars we can see with the naked eye from Earth all belong to our own galaxy. The stars that our eyes can resolve as individual points are in our immediate galactic neighborhood, at most a few hundred to a few thousand light-years away. What we see on clear nights as a glowing band in the sky, commonly referred to as the „Milky Way“, is the projection of the main disk of our galaxy, where most stars are concentrated, onto our celestial sphere. The stars that we can no longer perceive individually are mostly very far away; the center of our star system is about 26,000 light-years away. Other galaxies, however, are at distances of millions to billions of light-years. The Andromeda Galaxy, our neighboring galaxy, is about 2.5 million light-years away.

How the night sky affects the lives of humans and animals

It is plausible to assume that gazing at the night sky has long been an inspiration for the human spirit. Artifacts such as the Nebra Sky Disk[6] suggest that humans have been engaged with the night sky for thousands of years. Furthermore, the starry sky has had practical significance throughout human history.

About sailors

As an example, I will highlight navigation at sea: Humans learned to navigate by the stars a long time ago. Sailors in the Pacific probably practiced navigation techniques thousands of years ago that allowed them to travel between the widely separated islands of Micronesia and Polynesia. These techniques included observing birds, ocean waves, and wind patterns, as well as navigating by the stars[7]. This knowledge was passed down orally from generation to generation.

To find out to what extent this tradition has survived into modern times, world sailor and adventurer David Lewis visited several island groups in the Pacific in the 1970s and made contact with locals. He interviewed people knowledgeable in navigation and undertook longer canoe journeys on the open ocean with them to learn the navigation techniques firsthand. In his book „We, the navigators: the ancient art of landfinding in the Pacific”[8] he extensively documented his findings. An important method to maintain orientation during the journey between two islands is to use stars or constellations that are just above the horizon. Particularly, stars in exact eastern and western directions offer the advantage of rising or setting vertically there[9]. Stars in the north and south, on

the other hand, have the practical significance of maintaining their position year-round - at least approximately[10].

A device developed in connection with this navigation technique is the „star compass“ (sidereal compass). Compass points there represent the position of selected stars (so-called „steering stars“ or „guiding stars“) at their rising or setting. An example of such a device is documented in the Caroline Islands („Carolinian star compass“)[11]. This island chain stretches east of the Philippines for more than 2000 kilometers at approximately 7° north latitude. Due to its location just north of the equator, the Pole Star (Polaris) can be seen slightly above the horizon directly to the north, and its position changes only slightly over time. Therefore, Polaris is registered as the northern compass point on the star compass commonly used in this region. The southern celestial pole is no longer visible from the Carolines, but the Southern Cross, a constellation near the southern celestial pole – approximately 25° away from it – can be seen from the island group at certain times in the south, as it moves in a small semicircle around the southern point. To optimally support sailors navigating southward in the vicinity of the Carolines, several compass points with the Southern Cross are therefore marked on the star compass[12].

The history of sea navigation in 18th century Europe is inseparably linked with the development of highly accurate chronometers. Seafarers can relatively easily determine latitude (how far north or south of the equator they are) by observing the height of the celestial pole[13]. However, to determine longitude (how far west or east their course is), one also needs to know the precise time. An example illustrates this: A star that sets in the west at a certain time on the prime meridian (passing through the Royal Observatory in Greenwich, London) will still be at a certain height above the horizon for an observer simultaneously further west on the Atlantic. The precise height at a certain time depends on the longitude of the observer. The highly readable book „Longitude“ by American science writer and author Dava Sobel[14] vividly describes the quest for a method to determine longitude at sea in the 18th century. The book focuses on John Harrison, a self-taught clockmaker who, against all odds, developed a precise marine chronometer that revolutionized navigation.

This detail from the history of science and technology immediately illustrates how much the sight of the night sky gives us „an irresistible feeling of machinery, clockwork, elegant precision“, as Carl Sagan expressed in the quote cited at the beginning.

Animals in the planetarium

But it's not just for humans; the night sky also plays a significant role for the animal kingdom. I'll highlight two examples[15].

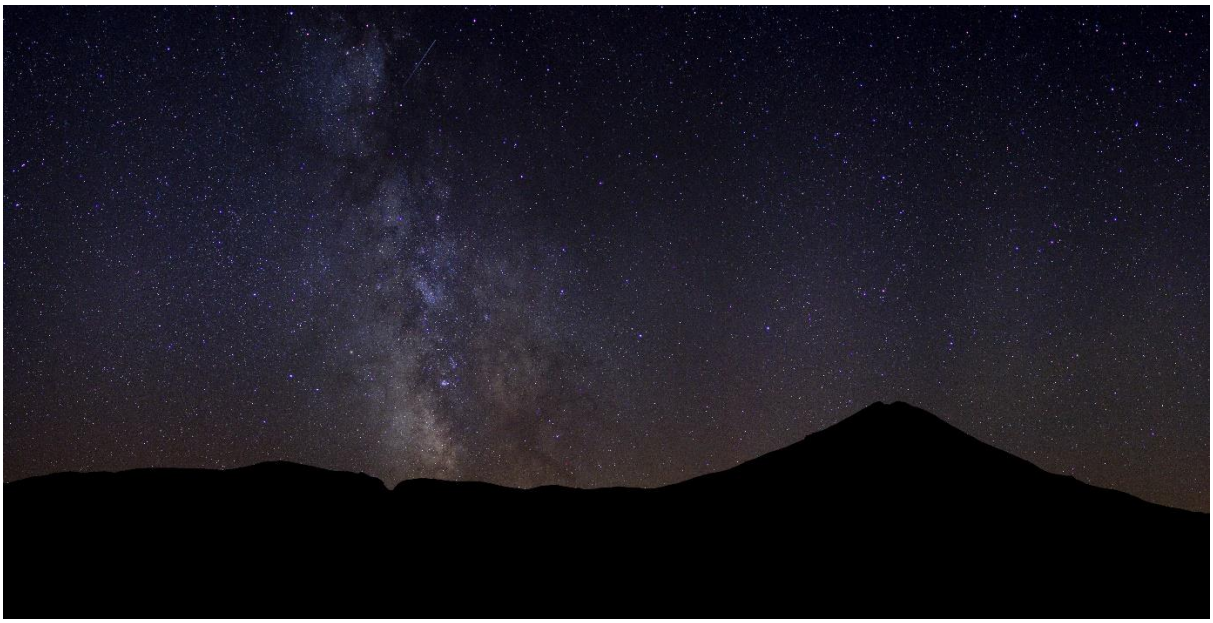
Migratory birds[16] can navigate during starry nights by orienting themselves around the rotational center of the starry sky. They seemingly remember star patterns around this point in the sky and compare them with the currently observed star formations. A study from 2001[17] investigates the behavior of pied flycatchers (Ficedula hypoleuca) and blackcaps (Sylvia atricapilla), which was observed in a planetarium. The results of the experiment suggest that birds use a time-independent star compass based on learned geometric star configurations to accurately determine the rotation point of the night sky.

Among us humans, those knowledgeable about astronomy can also easily orient themselves using the pattern of the circumpolar stars[18] and effortlessly find the celestial pole. One trick to visualize this directly is to take a long-exposure photograph of the sky, in which the stars, due to the Earth's rotation, form light trails—star trails.

Star trails seen in the Vosges, France; in high resolution:
https://www.silberspur.de/topics/astro/climont-circumpolar.jpg

A beetle species living in South Africa may even navigate by the Milky Way[19]: the dung beetles of the species Scarabaeus satyrus detach a piece of dung from a pile, shape it into a ball, and roll it away along a straight path to protect their food from competitors. These beetles are able to maintain their direction even on starry nights without a moon in the sky. However, they lose this ability when the sky is overcast at night. This suggests that the beetles navigate using the starry sky in the dark. However, much evidence indicates that Scarabaeus satyrus does not navigate by star constellations but rather by large-scale differences in the brightness of the sky, such as those created by the band of the Milky Way. This strategy offers the advantage of being robust against changes in atmospheric conditions and relatively independent of star patterns, whose positions depend on the time of year and the time of day.

The following image shows the band of the Milky Way over the Cantal Mountains in the French Massif Central.



Milky Way above the Cantal, France; in high resolution: https://www.silberspur.de/topics/artificial-light-at-night/puy-mary.jpg

Light pollution from terrestrial light sources

The experience of the natural night sky is increasingly being disrupted by artificial human-made light sources, a phenomenon also known as „light pollution“[20]. The largest contributors to this are the lights of our cities and the light emitted during other activities, such as driving at night.

The following photo was taken on the Hornisgrinde in the Black Forest, Germany, at an altitude of 1150 meters above sea level.

Artificial light seen from Hornisgrinde, Black Forest; in high resolution:
https://www.silberspur.de/topics/artificial-light-at-night/hornisgrinde-orion-venus-mars.jpg

In the sky, just to the left of the center of the image, the constellation Orion is prominently visible. Additionally, a very special planetary alignment is depicted: in the upper left of the image is Jupiter, near the horizon on the right is the setting Venus, and directly above it is Mars.

The lower part of the image is characterized by many different human-made light sources. On the right, the lights of villages in the adjacent Black Forest valleys shine through the fog in a yellow color, while the artificial lights in the background on the right come from the densely populated Rhine Valley. On the left side of the image, the floodlights of nearby ski lifts emit a bright bluish light into the sky. Further left (no longer in the image), the light from another ski lift scatters in the atmosphere, significantly impairing the view of the starry sky. The light even reflects off the snow at my photo location, several kilometers away. Incidentally, the ski lifts are located directly next to the Black Forest National Park.

„Light pollution is one of the most pervasive forms of environmental alteration. It affects even otherwise pristine sites because it is easily observed during the night hundreds of kilometres from its source in landscapes that seem untouched by humans during the day, damaging the nighttime landscapes even in protected areas, such as national parks."[21]

The following photo provides a good impression of how far light pollution from urban areas can extend spatially. Here, the effect is further amplified by high cirrus clouds that reflect the light. The photo was taken near the Grand Mont Rond in the French Jura, at an altitude of approximately 1600 meters above sea level.

View from Grand Montrond, Jura, France; in high resolution:
https://www.silberspur.de/topics/artificial-light-at-night/grand-montrond.jpg

The photo was taken in a southerly direction. The lights shining from below the fog at left belong to the metropolitan area of Geneva, in a distance of about 20 kilometers. The dark mountain silhouette in the center of the image is the range of Crêt de la Neige, the highest peak in the Jura mountains.

The artificial lights at right reflected by the clouds originate from the metropolitan area of Lyon more than 100 kilometers remote[22].

The following photo shows how a very nearby urban area influences nocturnal landscape photography. It was taken on a clear winter night on the Grand Ballon, the highest peak of the Vosges Mountains at about 1400 meters above sea level, facing east. The mountain massif borders directly on the densely populated Alsace region, and one looks down from above on the Colmar area. The image may have an aesthetic appeal, also and especially because of the anthropogenic light sources beneath the fog, but it also demonstrates how dramatically our civilization has altered the night sky. This panorama is composed of several individual shots taken consecutively with the same exposure time.

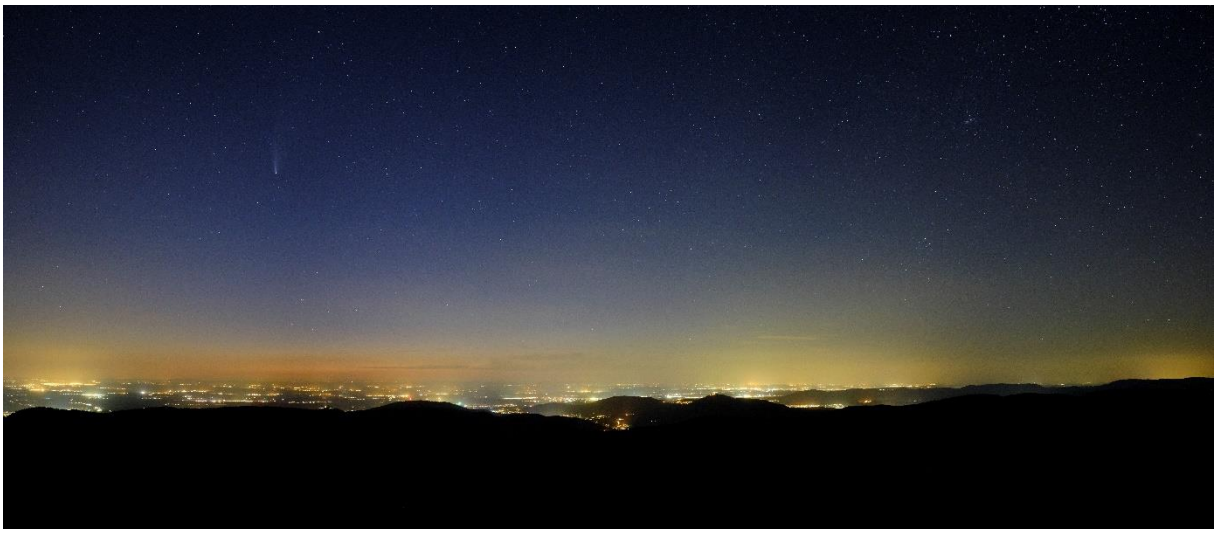
View from Grand Ballon, Vosges, France; in high resolution:
https://www.silberspur.de/topics/artificial-light-at-night/grand-ballon-milky-way.jpg

Why the increase in artificial stray light at night also represents a form of increased entropy can be understood by listing some of the consequences: natural darkness is replaced by "disordered" stray light, biological rhythms and ecological systems are disrupted, and energy is converted into heat.

Using artificial light creatively in night landscape photography

I would like to demonstrate with a photo how artificial light sources can be creatively integrated into night landscape photography.

The following photo was taken in the northern Black Forest, Germany, at an altitude of 1000 meters and shows the view northward towards the densely populated Rhine plain, including the metropolitan area of Karlsruhe. I deliberately chose this location so that an area with a lot of artificial light – combined with well-recognizable mountain silhouettes – can be seen on the horizon.



Comet Neowise above the Rhine valley; in high resolution: https://www.silberspur.de/topics/artificial-light-at-night/northern-black-forest-neowise.jpg

The main subject of the picture is the comet „Neowise“ (top left), which was visible in Europe during the summer of 2020. I intended to show the comet with a regional context. Therefore, I chose this location for the shot. Since the entire mountain landscape to the north is significantly lower than my observation point, you can get a particularly good view of the foothills of the Black Forest and the Rhine plain behind it. Locals familiar with the area can recognize the individual towns and mountain peaks. The photo was also printed in a regional daily newspaper; for residents of this area, it was likely interesting to learn that they could observe the comet from their „home“.

Atlas of light pollution

If you want to find out which regions on Earth are particularly affected by artificial light in terms of experiencing the night sky, and in which areas you can still enjoy an unobstructed night sky, there is now plenty of information available online. I will highlight a few of these resources.

For many years, satellites have been detecting artificial light sources on Earth. In 2011, the „Suomi National Polar-Orbiting Partnership (NPP)“ satellite was launched, which carries a radiometer for the visible and infrared range (Visible Infrared Imaging Radiometer Suite, abbreviated: VIIRS).

The data is published by NASA under the keyword „Black Marble“[23]. The same data forms the basis for an online version of the „light pollution map“[24]. A world atlas of light pollution published in 2016 uses VIIRS data[25]:

„This atlas shows that more than 80% of the world and more than 99% of the U.S. and European populations live under light-polluted skies. The Milky Way is hidden from more than one-third of humanity, including 60% of Europeans and nearly 80% of North Americans. Moreover, 23% of the world's land surfaces between 75°N and 60°S, 88% of Europe, and almost half of the United States experience light-polluted nights.“

One could say that a third of humanity lives in places where the Milky Way can no longer be seen.

Satellites, whose data form the basis for the aforementioned light pollution map, can measure light emitted upwards. However, they do not provide information about horizontally emitted light. Therefore, they can only partially represent the light pollution perceived from Earth. A study[26] involving citizen scientists who were asked to assess the degree of light pollution at their location can

supplement the satellite data. This study concludes that in recent years, the brightness of the night sky has approximately doubled every eight years.

One might think that in the still „dark“ areas far from urban lighting, one can enjoy an unobstructed starry sky. Unfortunately, this is not the case, as there are other sources of interference that are not located on the Earth's surface: airplanes and satellites. Photographers who take long series of images of the night sky, for example, for time-lapse shots, may not be too pleased about this.

Light pollution from airplanes and satellites

Airplanes create light trails in the sky with their position lights. Satellites shine when they are at high altitudes, still illuminated by the sun, reflecting light onto the already dark Earth's surface. Therefore, the hours before sunrise and after sunset are most affected by this latter effect. In long-exposure photographs of the night sky, airplanes typically appear as dotted lines stretching across the entire sky to the horizon. Satellites, on the other hand, leave continuous lines that usually disappear at a certain point in the sky when the satellite enters the Earth's shadow. The artificial light from airplanes and satellites also affects the natural night sky even in places far from terrestrial artificial light sources.

I took the following star trail photo in the Southern Black Forest, Germany, near the Herzogenhorn.

Star trails and airplanes above the Black Forest; in high resolution:
https://www.silberspur.de/topics/artificial-light-at-night/krunkelbachsterne.jpg

The southern Black Forest is particularly affected by air traffic[27]. This is immediately apparent in the star trail photograph.

Satellites can be interesting in night-time photos when they appear as „flares“ – sudden bright spots. This effect occurs when a satellite or another object in space strongly reflects sunlight with a surface.

As the orientation of this surface changes relative to a fixed observation point on Earth during its orbit, the beam of reflected sunlight briefly sweeps across certain observation locations. Here‘s an example of this phenomenon.

Flare; in high resolution: https://www.silberspur.de/topics/artificial-light-at-night/satellite-maix.jpg

The following star trail photo shows the northern circumpolar stars.

Star trails and ISS; in high resolution: https://www.silberspur.de/topics/artificial-light-at-night/startrails-ruhestein-iss.jpg

The photo was taken in the Bannwald near Ruhestein in the northern Black Forest. But what is flying through the image? Right, you guessed it, it's the International Space Station (ISS)[28].

Photos like these can have their own unique charm. However, the rapidly increasing number of satellites could have long-term undesirable effects, primarily on ground-based astronomical observations. As the preceding photos suggest, satellites can disrupt astronomical observations by leaving light trails on images. They can also degrade the quality of observations by making the sky overall brighter due to their increasing numbers.

There are already thousands of satellites in low Earth orbit. SpaceX's Starlink satellites currently dominate the scene[29], and SpaceX plans to deploy a four-digit number of satellites into orbit in the next few years.[30]

Scientists[31] have simulated how the night sky might change with an estimated increase in satellite density. They modeled the brightness and distribution in the sky for a potential future with 65,000 satellites. This number was estimated based on currently available information about satellite operators (with information on orbits submitted by companies like Starlink, OneWeb, Kuiper/ Amazon, and StarNet/GW).

Firstly, this study provides an estimate of the number of visible satellites for different latitudes and seasons. Secondly, by considering the brightness influenced by the position in space and the angle of incident sunlight, it estimates how the apparent brightness of the sky will be affected by satellites. The impact on ground-based astronomical observation is discussed, and the authors suggest that the overall brightness of the night sky will increase. A simple calculation results in a value of 4%.

„The first feature that is immediately obvious is that latitudes near 40°N and S have the most sunlit satellites (…) But due to Earth's shadow, there is a period of few-to-no sunlit satellites for ~5–6 hr around midnight during the winter at these latitudes. However, during summer, there are more than a thousand sunlit satellites above the horizon all night long."

According to another study[32], the brightness of the entire sky due to „space debris" – fragments created, among other things, by the collision of satellites – has already increased by 10% above pre-industrial levels:

„According to our preliminary estimations, this newly recognized skyglow component could have reached already a zenith visual luminance of about 20 µcd m−2, which corresponds to 10 per cent of the luminance of a typical natural night sky, exceeding in that way the IAU's limiting light pollution 'red line' for astronomical observatory sites. Future satellite mega-constellations are expected to increase significantly this light pollution source."

Another problem is satellites that are particularly bright. The „BlueWalker 3" satellite, a commercial communications satellite from the US company AST SpaceMobile, is one of the largest satellites ever launched into space and thus one of the brightest objects in the night sky. Depending on the orientation of the antenna relative to the observer, the satellite can reach a maximum apparent brightness of +0.4 mag[33]. The International Astronomical Union (IAU) recommends that satellites in low Earth orbit should not exceed a maximum apparent brightness of +7 mag[34]. Therefore, the maximum apparent brightness of BlueWalker 3 exceeds the IAU's recommended limit by more than 400 times[35].

There are also initiatives that aim to counteract this development. The SATCON2 group[36] brings together various stakeholders to work together on an ethical, legal, and regulatory framework for the protection and sustainability of space. The Canadian astronomer Samantha Lawler, who advocates for the protection of the natural night sky, states[37]:

„I often wonder what kind of night sky my children will inherit. Will the stars be hidden behind a rawling grid of bright satellites, or a hazardous snow globe of post-Kessler debris? Or will government regulators set strong safety and light-pollution rules before the night sky is all but lost? The future sky will be chosen in the coming years by the actions of private satellite companies and the government agencies that should be regulating them.“

With a recently established initiative called the „Kessler Rebellion“[38], researchers, including Samantha Lawler, are trying to mobilize the public against the uncontrolled deployment of very bright satellites and to work towards regulating this development.

But why „Kessler“? I will briefly address this in the next section.

Will low earth orbit become unusable soon? The so-called „ Kessler Syndrome“

We have seen that the increasing density of satellites in low Earth orbit is becoming a growing problem for researchers, particularly in astronomy. This development could also become a serious problem for space travel in the future.

In the 1970s, astronomer Donald J. Kessler[39] investigated the effects of an increasing number of satellites in low Earth orbit and the associated likelihood of collisions. To estimate future developments, he applied statistical models that describe the formation of the asteroid belt between Mars and Jupiter to low Earth orbit.

Kessler concluded that satellite collisions would produce numerous fragments that could destroy additional satellites. This could lead to an exponential increase in the number of objects and the formation of a belt of space debris around the Earth. This process is similar to the one that likely formed the asteroid belt but would occur much faster in low Earth orbit due to the smaller spatial dimensions.

In detail, Kessler found that the collision-induced destruction of satellites could soon lead to a debris stream that exceeds the natural meteorite flow in certain regions (without a specific time estimate). In the long term, the amount of debris would increase exponentially.

This phenomenon became known as the „Kessler Syndrome“. However, this term was never introduced into the scientific discussion by Donald J. Kessler himself[40].

The crucial question now is: could the currently expected increase in the number of satellites in low Earth orbit soon lead to the formation of a debris belt that makes the use of low Earth orbit practically impossible?

A recent study[41] cautiously concludes:

„In line with previous studies, our model finds that debris congestion may be reached in less than 200 years, though a holistic management strategy combining removal and mitigation actions can avoid such outcomes while continuing space activities.”

In a 2023 paper[42], the so-called KESSYM model (KESsler Syndrome Model) is presented and thoroughly explained. KESSYM uses data on the population and flux of space debris, provided by existing works from ESA and NASA, as input[43]. For calculating future developments, KESSYM employs

statistical methods to simulate the collision probability between three types of objects in orbit: satellites, satellite fragments (debris), and micro-fragments (<1kg). These objects are treated as particles of an ideal gas, allowing the collision probabilities to be simplified and calculated based on the „gas density".

„Orbital mechanics and collisions are modeled on a probabilistic basis based on a 'density' of objects in the LEO, rather than by tracking exact flight paths."

Die Arbeit kommt zu dem Ergebnis, dass das Kessler-Syndrom „… is almost an inevitability within 200-250 years of today's date, but can be delayed or avoided altogether if action is taken."

There are now indications of another, potentially more threatening risk from satellite mega-constellations: falling space debris creates nanoparticles of aluminum and aluminum oxide, which, once they have descended into the stratosphere over decades, could damage or even completely deplete the ozone layer. This would be an absurd irony of history, as the ban on fluorocarbons in the 1980s was one of humanity's few successful global initiatives that stopped an imminent planetary change – namely, the depletion of the ozone layer[44].

Effects of light pollution beyond astronomy and photography

There is little doubt that artificial light at night has significantly increased in recent years and will continue to do so[45]. Although it can be creatively used in nighttime landscape photography, as shown, the negative impacts should not be underestimated.

Quite obviously, light pollution disrupts the work of astronomers and astrophotographers. This group of people, akin to the „canary in the coal mine"[46], is the first to raise the alarm when something is amiss. Just as the sudden silence of the canary in the mine is a warning signal for something larger and more serious, the complaints of astronomers should be taken seriously. Because artificial light at night, when it exceeds a certain level, indeed has far-reaching consequences and implications.

To begin with Homo sapiens: This review[47] summarizes potential health risks that may be associated with light pollution. According to the authors, it is plausible that artificial light primarily affects the circadian rhythm[48] (also known as the „internal clock") in humans. From this, the possible consequences could include: disruption of the sleep-wake cycle, impacts on the electrical activity of the brain, neurodegeneration, and other biological processes. According to the scientists, all of this could even contribute to the development of Alzheimer's disease.

Now, let's take a brief excursion into the animal kingdom.

To what extent the dung beetle Scarabaeus satyrus, which we have already encountered, is affected by increasing light pollution would be an interesting question. Further investigations would likely be necessary to determine, for example, whether the beetle's habitats overlap with areas of high light pollution. If artificial light mainly affects the near-horizon areas of the sky, the view of the Milky Way might still be sufficient, so the nocturnal orientation aid for the animals would not be impaired. However, if the light pollution is so severe that the Milky Way is no longer visible at all (as is typically the case in metropolises), this could become problematic[49].

However, it is plausible to assume that light pollution significantly impacts the animal and plant world simply because it disrupts the natural transition between day and night. There is a vast amount of scientific literature on this topic. As an example, let's consider a study[50] that tested the hypothesis that light pollution disturbs animal sleep, using great titmouse as a case study. The sleep behavior of animals exposed to artificial light on some nights was compared to that of a control group that always

slept in darkness. Artificial light caused the test birds to wake up earlier, sleep less, and spend less time in the nesting box.

An overview article[51] in the online magazine „The Conversation“ particularly addresses the problem that artificial light sources can act as deadly traps for insects. The insects circle the light incessantly, are unable to find food, are easily discovered by predators, and tend to exhaust themselves. Many die before morning comes. Another review article[52] in „ScienceDirect“ discusses the impact of artificial light at night on insects in greater detail. It reviews studies that examine the effects on various aspects of insect life, such as reproduction, migration, and predation.

Another article[53] reports that light pollution surprisingly also affects a fish species living in shallow coastal waters in New Zealand[54].

The impact of our actions on the night sky is of far-reaching significance and can be viewed within the context of the global, planetary changes we associate with the term „Anthropocene“. This term was introduced into the discussion in the early 2000s by, among others, the Dutch chemist and atmospheric researcher Paul Crutzen[55], and found its way into media coverage of topics such as the climate crisis and environmental protection. It signifies that humans have become one of the most important factors influencing biological, geological, and atmospheric processes on Earth—a planetary influence. However, the proposal to formally designate the „Anthropocene“ as a new geochronological epoch was rejected by the International Commission on Stratigraphy[56] in March 2024 for various reasons[57].

What can we do?

We have seen that the natural dark night sky is a valuable asset, whose preservation is threatened by the increasingly dense population of the Earth, the growing number of artificial light sources, the use of brighter artificial lights, and the congestion of the near-Earth orbit by satellites. Shouldn't access to a natural night sky even be considered a human right that needs protection? The organization „DarkSky International“ puts it this way:

„We believe the natural nighttime environment is a basic human right — for every person for all time — celebrated in diverse communities' cultures and heritage. Light justice requires responsible lighting and access to a night free of light pollution, for everyone.“[58]

Indeed, several initiatives have formed in recent years with the goal of protecting this asset. Moreover, there are now successful efforts to designate certain regions of the Earth as „light protection areas“.

Light protection areas

In a light protection area, measures are taken to minimize the negative impacts of artificial light and thus protect the natural night sky. The communities within a light protection area follow specific lighting regulations and use technologies to limit the amount of emitted light. Additionally, many of these protected areas conduct public outreach to raise awareness among visitors about the issue—similar to what is done in national parks and biosphere reserves.

Originally, initiatives to protect the natural night light were driven by astronomy. This is understandable, as their daily – or should we say nightly – business involves studying the starry sky. To protect large observatories from disruptive urban light pollution, protective zones were contractually agreed upon with the relevant regional authorities. For example, a corresponding legal basis was established for the islands of La Palma and Tenerife in the Canary Islands. Since then, various countries have established light protection areas. Canada, for example, founded the Torrance

Barrens Conservation Area and Dark Sky Reserve[59]. Several European countries followed this example in the 2000s, including Scotland and Hungary[60].

The „light protection movement“ received further impetus at a conference in La Palma in 2007. There, the concept of „UNESCO-Starlight Reserves“ was developed, modeled after the idea of biosphere reserves[61], and the Starlight Foundation was established[62].

“An unpolluted night sky that allows the enjoyment and contemplation of the firmament should be considered an inalienable right of humankind equivalent to all other environmental, social, and cultural rights, due to its impact on the development of all peoples and on the conservation of biodiversity.”

As another important step, it was determined at the UNESCO World Heritage Conference in Brasília in 2010 that a „dark night sky for astronomy“ is also a worthy object of protection[63].

Today, there are several organizations independently working on concepts for light protection and developing corresponding classification systems: UNESCO, the Dark Skies Advisory Group[64] of the International Union for Conservation of Nature, and DarkSky International[65].

Noteworthy is the international project „The World At Night“[66], which specializes in producing and presenting artistically appealing photographs, films, and animations of the night sky over natural, cultural, and historical monuments worldwide.

Light protection areas in Germany

There are a few such protected areas in Germany, including the UNESCO Rhön Biosphere Reserve[67], which has been designated a „Star Park“ by the International Dark Sky Association. An example of how light protection is implemented in this region: The municipalities located within the Rhön Star Park have voluntarily committed to reducing public lighting as much as possible and adjusting it to actual needs. Measures include targeted light direction (instead of emitting large amounts of light upwards into the sky), warm light colors (instead of bright blue), adjusted light quantities, and needs-based and targeted lighting. To support the municipalities, as well as local businesses and private households in planning and implementation, extensive informational material is offered free of charge. For instance, one brochure explains that solar lights in gardens – as popular as they are – are usually intended as decoration rather than as light sources and can cause additional stress for insects.

Further light protection areas in Germany include: the Eifel Star Park[68], the Winklmoosalm Star Park near Reit im Winkl[69], the Westhavelland Nature and Star Park[70], and Germany's first „Star City“, Fulda[71]. Planned and partly in the project phase are the Schwäbische Alb Star Park[72] and the Nossentiner/Schwinzer Heide Nature Park[73].

A well-known light protection area in France is the mountain region around the Pic du Midi in the Pyrenees, which has been designated an „International Starry Sky Reserve“ by the International Dark Sky Association[74]. A unique approach is being taken in the metropolis of Strasbourg[75]. In 2022, the city began reducing street lighting where possible without compromising traffic safety. This gradual approach aims to establish more sustainable and energy-efficient lighting.

Perhaps humanity will manage to preserve the dark night sky. Naturally dark skies, like clean air and clean water, are a resource to which everyone has a right. In the future, no one should be deprived of the experience of the night sky, which Carl Sagan[76] described so wonderfully.

“Even today the most jaded city dweller can be unexpectedly moved upon encountering a clear night sky studded with thousands of twinkling stars. When it happens to me after all these years it still takes my breath away.”

Peter Gutsche | www.silberspur.de

[1] Sagan, C. (1994): Pale Blue Dot: A Vision of the Human Future in Space. Ballantine Books, The Random House Publishing Group (Chapter 8)

[2] Suppose Earth, like Venus, had been permanently covered by dense clouds for billions of years. Intelligent, self-aware life would have evolved there, shielded from a starry sky as we know it. Would these beings eventually have begun to engage in astronomy? Would religions have emerged, along with technology? To be precise, let's, for simplicity, assume an atmosphere like Earth's with a cloud cover made of water droplets, but one that would permanently shroud the planet's surface. Visible light and higher-frequency electromagnetic radiation would be absorbed by such an atmosphere through the cloud cover after a short distance. Longer-wavelength radiation in the radio wave range can penetrate clouds. However, there is currently no evidence that animals on Earth have developed a sense for radio waves (except that radio waves apparently can disrupt the magnetic sense of migratory birds), see: Vácha, M., Půžová, T., Kvíćalová, M. (2009): Radio frequency magnetic fields disrupt magnetoreception in American cockroach. J Exp Biol (2009) 212 (21): 3473–3477 (https://journals.biologists.com/jeb/article/212/21/3473/18994/Radio-frequency-magnetic-fields-disrupt)). This is plausible, because the energy of radiation in the radio wave spectral range is way too low as it would allow to change any electronic states in molecules. However, there's the need for further research and investigation, see: https://www.bfs.de/DE/bfs/wissenschaft-forschung/emf/stellungnahmen/emf-tiere-und-pflanzen.html. Apart from the fact that an intelligent species would then have developed without the sensory experience of the starry sky: perhaps under such a permanent cloudy sky, they would first start practicing radio astronomy. Who knows.

[3] This footnote comments on the countless footnotes that can still be found on the following pages. The text can – I hope – be read profitably without them. The footnotes are intended for those who wish to delve deeper into a particular topic. In most cases, there are references to scientific papers. There is an overwhelming abundance of works on this subject, and I, as a scientific layman, have tried to select some representative studies. If anyone notices an error, a misjudgment, or an important omission, I would be very grateful for any feedback (mail@silberspur.de).

[4] I took the above photo on the Hornisgrinde in the northern Black Forest. The lights under the fog are from the Greater Strasbourg area in the Rhine Valley. In high resolution: https://www.silberspur.de/topics/light-pollution/hornisgrinde-fog.jpg.

[5] All the photos shown here are exclusively taken by me.

[6] See: https://www.landesmuseum-vorgeschichte.de/himmelsscheibe-von-nebra.html.

[7] Of course, the sun during the day and the moon at night also provide help with orientation. Since the sun, moon, and earth move relative to each other over the course of the year, the rising and setting positions of the sun and moon on the horizon change significantly over the course of a year or a month. The stars, although they seem to rotate around the earth as a whole once every 24 hours, retain their positions relative to each other throughout the year. Stars always rise and set at exactly the same place. Therefore, this is referred to as the fixed star sky. However, it is not entirely true that the fixed star sky has remained unchanged throughout human history. Two phenomena can be mentioned here that have an influence. On the one hand, the Earth's axis undergoes a slow wobbling motion approximately every 26,000 years, known as the precession of the Earth's axis. Therefore, the positions of the celestial poles relative to the star constellations change significantly over a time scale of several thousand years. Thousands of years ago, the North Star was not located at the celestial north pole. On the other hand, the stars move within the galaxy over very long periods (we are talking about hundreds of millions of years) around the galactic center. Hence, the apparent position of very nearby stars changes over time, and with it the constellations themselves. It would certainly be interesting to research whether these effects can be found and reconstructed in very early records of celestial navigation. By the way, the precession of the Earth's axis was discovered by Hipparchus (born around 190 BC) by comparing star positions determined in his time with observations of earlier astronomers. In doing so, he referred to data on lunar occultations: events where the positions of stars in the zodiac could be determined very precisely. He noticed that the positions of the stars shifted slowly but continuously, indicating that the Earth's axis slightly shifted over time.

[8] Lewis, D. (1972): We, the navigators : the ancient art of landfinding in the Pacific. Australian National University Press.

[9] Near the equator, this includes the prominent constellation Orion, for example.

[10] We are talking about regions near the equator, where the northern and southern celestial poles are relatively close to the northern and southern horizons, respectively. More on that later.

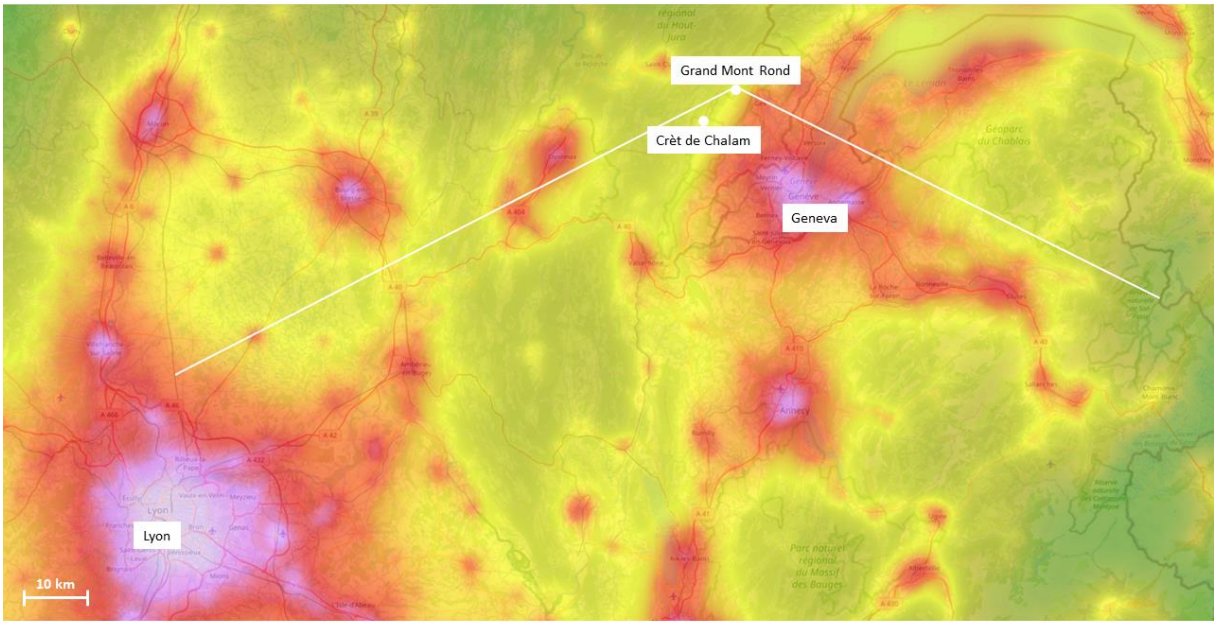
[11] See: Lewis, D. (1972): We, the navigators : the ancient art of landfinding in the Pacific. Australian National University Press. Kapitel 4.
[12] On the following page, it is described in detail how to use a star compass: https://archive.hokulea.com/ike/hookele/on_wayfinding.html. The page is owned by Charles Nainoa Thompson, a Hawaiian navigator. He is the first Hawaiian since the 14th century to practice the ancient Polynesian art of navigation. He navigated from Hawaii to other island nations in Polynesia without the help of modern instruments.
[13] On the Northern Hemisphere, one navigates using the North Star (Polaris), and on the Southern Hemisphere, one can easily determine the celestial pole near the Southern Cross. For more information about the „star compass“: https://archive.hokulea.com/ike/hookele/on_wayfinding.html.
[14] Sobel, D. (1995): Longitude: The True Story of a Lone Genius Who Solved the Greatest Scientific Problem of His Time. Walker & Company.
[15] There is a confusingly large number of studies on the influence of the night sky on wildlife. The following article provides a good overview of examples from the animal kingdom with many references to publications: Foster, J.J., Smolka, J., Nilsson, D.-E. und Dacke, M. (2018): How animals follow the stars. Proceedings of the Royal Society B: Biological Sciences, Volume 285 (https://royalsocietypublishing.org/doi/10.1098/rspb.2017.2322).
[16] Ein Beispiel: Emlen S. (1967): Migratory orientation in the Indigo Bunting, Passerina cyanea. Part II: mechanism of celestial orientation. The Auk, Volume 84, Issue 4, 1 October 1967, Pages 463–489. (https://academic.oup.com/auk/article/84/4/463/5198008).
[17] Mouritsen, H., Larsen. O.N. (2001): Migrating songbirds tested in computer-controlled Emlen funnels use stellar cues for a time-independent compass. Journal of Experimental Biology (https://journals.biologists.com/jeb/article/204/22/3855/32913/Migrating-songbirds-tested-in-computer-controlled). The animals were observed in a so-called Emlen funnel in a planetarium. The Emlen funnel was developed in 1966 by Stephen Thompson Emlen and John Thompson Emlen to observe and systematically study the behavior of birds during migratory restlessness. The device consists of a funnel-shaped container in which a bird can be placed. To prevent the bird from flying away, a net is attached to the top of the funnel. In the original version of this apparatus, the funnel is prepared so that the bird leaves marks in a medium such as ink or thermal paper when it hops up. These marks can later be analyzed in terms of frequency and direction. For the cited recent study, the scientists developed a computer-assisted Emlen funnel, which allowed continuous monitoring of the birds without disturbing them. John Thompson Emlen and Stephen Thompson Emlen are American biologists. John Thompson Emlen lived from 1908 to 1997 and is the father of Stephen Thompson Emlen, an American ornithologist and Emeritus at Cornell University.
[18] This term refers to the stars near the celestial pole that never set throughout the night. Exactly at the Earth's poles, the entire visible night sky consists of circumpolar stars – they never rise or set. Exactly on the equator, there are no circumpolar stars – the celestial poles lie exactly on the horizon (to the north and south). Returning to the Caroline Islands: There, at 7° northern latitude, the (northern) circumpolar stars are limited to a small circle with a radial distance of 7° from the northern celestial pole. In Germany, at approximately 50° northern latitude, this circle is significantly larger.
[19] In a study, the behavior of the animals was investigated at the Johannesburg Planetarium. The beetles were released with their dung balls from the center of a circular area of flat, level sand, surrounded by a circular wall. The movement of the animals was filmed from above with an infrared camera. The time taken to roll from the center of the arena to the edge was used as an indicator of the straightness of their path. The experiment was conducted under various conditions with different artificially projected night skies: many stars and the Milky Way visible, only the Milky Way visible, only the brightest stars visible, and complete darkness. The results suggest that on a dark, moonless night, the brightness band of the Milky Way alone is sufficient as a navigational aid for the animals. See: Dacke, M., Baird, E., Byrne, M., Scholtz, C.H., Warrant, E. J. (2013): Dung Beetles Use the Milky Way for Orientation, Current Biology 23, 298–300, February 18 (https://www.cell.com/current-biology/fulltext/S0960-9822(12)01507-2). A newer study: Foster, J. J., el Jundi, B., Smolka, J., Khaldy, L., Nilsson, D.-E., Byrne, M. J. und Dacke, M. (2017): Stellar performance: mechanisms underlying Milky Way orientation in dung beetles, Phil. Trans. R. Soc. (https://royalsocietypublishing.org/doi/10.1098/rstb.2016.0079). In this study, beetles were placed in a kind of mini-planetarium and their behavior was observed under different lighting conditions. The scientists simulated the South African night sky based on calibrated fisheye images of the entire night sky taken in South Africa. The images were then filtered to represent the lighting conditions as perceived by the beetles' compound eyes, which see in a blurred manner. The study investigated which strategy the beetles use for orientation: a pattern

recognition strategy, fixing on the brightest point, or comparing with a memorized intensity gradient. The suggestion that the beetles use the latter strategy is supported by the fact that Scarabaeus satyrus has relatively weak visual acuity in favor of higher light sensitivity.

[20] In English, also the term „artificial light at night“ (ALAM) is common.

[21] Quoted from Falchi,F., Cinzano, P., Duriscoe, D., Kyba, C.C.M., Elvidge, C.D., Baugh, K., Portnov, B.A., Rybnikova, N.A. und Furgoni, R. (2016): The new world atlas of artificial night sky brightness. Science Advances 2016 Jun; 2(6) (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4928945/).

[22] To illustrate the geographical context of this photo, I have marked the main reference points of the photo on the following map, which covers the area captured in the image. In order to illustrate the (satellite-measured) geographical distribution of artificial light, a layer from the light pollution map was also overlaid on this map (where areas with particularly high light pollution are shown in red to violet, and those with less artificial light are shown in green to yellow). From the comparison with this map, it is immediately clear that the bright light reflected by the clouds on the right side of the photo must come from the Lyon metropolitan area. However, the city itself remains hidden in the photo by the more distant Jura peaks and the hills in the Ain department. Lyon is more than 100 kilometers away from the vantage point where the photo was taken.



This map uses a screenshot from the online „Light Pollution Map“ (https://www.lightpollutionmap.info/) which is based on data from provided by Falchi,F., Cinzano, P., Duriscoe, D., Kyba, C.C.M., Elvidge, C.D., Baugh, K., Portnov, B.A., Rybnikova, N.A. und Furgoni, R. (2016): The new world atlas of artificial night sky brightness. Science Advances 2016 Jun; 2(6) (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4928945/). Furthermore, a layer from OpenStreetMap is used, see: https://www.openstreetmap.org/copyright. I get back to these „light pollution maps“ later in the text.

[23] See: https://blackmarble.gsfc.nasa.gov/.

[24] See: https://www.lightpollutionmap.info/.

[25] Falchi,F., Cinzano, P., Duriscoe, D., Kyba, C.C.M., Elvidge, C.D., Baugh, K., Portnov, B.A., Rybnikova, N.A. und Furgoni, R. (2016): The new world atlas of artificial night sky brightness. Science Advances 2016 Jun; 2(6) (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4928945/).

[26] Christopher C. M. Kyba et al. Citizen scientists report global rapid reductions in the visibility of stars from 2011 to 2022. Science 379, 265-268 (2023) (https://www.science.org/doi/10.1126/science.abq7781).

[27] Looking at https://www.flightradar24.com/48.55,6.55/7, you can find out that there's a high air traffic volume over the Southern Black Forest.

[28] I took the photo with the light trail on March 21, 2009, at 8:25 PM CET. As you can immediately see, the object flies just below Polaris, approximately 2° to 3° away. Since Ruhestein is at 48.5° north latitude, Polaris stands at an angle of 48.5° above the horizon. This means the overflying object has an angular height of about 45° at that location. Now, using simple trigonometry, one can see that the location where the ISS passes directly overhead (at the zenith) must be at a distance north of my position that roughly corresponds to the height at which the ISS is above the ground. A look at an ISS tracker site (http://www.isstracker.com/historical), where

historical data of the ISS can be accessed, shows that on that day and at that time, the ISS was flying over a place near the town of Paderborn in Northern Germany. This is 350 kilometers in a straight line from Ruhestein. And this matches quite well with the height the ISS had during this flyover according to the ISS tracker site (222 miles according to the site). Strictly speaking, one must also take the curvature of the Earth into account: the location where the ISS flies over the Earth is „below the horizon". However, this only accounts for about 10 kilometers according to a simple calculation, so it does not significantly change the result of our estimation.

[29] The temporal development from 2019 to 2023 can be clearly seen here: https://www.statista.com/statistics/1224164/starlink-satellite-launches/.

[30] Apart from the impact on the night sky, falling satellite debris apparently poses an increasingly „tangible" problem, as explained in this Canadian report: https://regina.ctvnews.ca/from-outer-space-sask-farmers-baffled-after-discovering-strange-wreckage-in-field-1.6880353. See as well: https://www.cbc.ca/news/science/space-debris-responsibility-1.7211473.

[31] Lawler, S.M., Boley, A.C., und Rein, H. (2022): Visibility Predictions for Near-future Satellite Megaconstellations: Latitudes near 50° Will Experience the Worst Light Pollution. The Astronomical Journal, 163:21 (14pp), 2022 January (https://iopscience.iop.org/article/10.3847/1538-3881/ac341b). See also the website of Prof. Samantha Lawler: https://uregina.ca/~slb861/about.html.

[32] Kocifaj, M., Kundracik, F., Barentine, J. C. und Bará, S. (2021): The proliferation of space objects is a rapidly increasing source of artificial night sky brightness, Monthly Notices of the Royal Astronomical Society (MNRAS), 504, L40 (https://academic.oup.com/mnrasl/article/504/1/L40/6188393). It should be noted that this study estimates the increase in sky brightness caused by space debris, which consists of countless smaller fragments. The number of satellites in space plays only an indirect role here, insofar as the amount of space debris increases with the number of active satellites in orbit (due to the risk of collisions).

[33] Nandakumar, S., Eggl, S., Tregloan-Reed, J. et al. The high optical brightness of the BlueWalker 3 satellite. Nature 623, 938–941 (2023) (https://doi.org/10.1038/s41586-023-06672-7).

[34] See: https://cps.iau.org/documents/41/Consolidated_Recommendations_for_Satellite_Operators_8.1.2023.pdf.

[35] Apparent brightness in astronomy is indicated with the unit mag (for magnitude), which is based on a logarithmic scale. And the brighter an object appears in the sky, the lower its magnitude value.

[36] Venkatesan, A., Lowenthal, J. D., Arion, D., Castro, F. A., Bannister, M., Barentine, J., Begay, D., Chavez, J.-C., Carttar, S. and various institutions: SATCON2: Community Engagement Working Group Report (2021). Astronomy: Faculty Publications, Smith College, Northampton, MA. (https://scholarworks.smith.edu/ast_facpubs/79). There: „The human right to see the naturally dark, unpolluted, starry night sky has been articulated in the Declaration in Defense of the Night Sky and the Right to Starlight (Starlight Foundation, 2007), and Resolution B5 in Defence of the Night Sky and the Right to Starlight (International Astronomical Union, 2009), and by the US National Park Service, which operates an extraordinarily popular Night Skies program whose motto is 'Half the Park is After Dark' and whose philosophy is that naturally dark skies are, like clean air and clean water, a natural resource to which every human has a right (National Park Service, 2021). Satellite constellations have the potential to dramatically and irrevocably alter the naked-eye appearance of the night sky."

[37] Lawler, S. (2023): Bright satellites are disrupting astronomy. Nature, Vol 623, pages 917-918 (https://www.nature.com/articles/d41586-023-03610-5.epdf.

[38] See: https://www.kesslerrebellion.com/.

[39] Kessler, D J., Cour-Palais, B G. (1978): Collision Frequency of Artificial Satellites: The Creation of a Debris Belt. Journal of Geophysical Research, Vol 83, pages 2637-2646 (https://doi.org/10.1029/JA083iA06p02637).

[40] Decades after the publication of the original work, Donald J. Kessler clarifies this in an article: Kessler, D. J., Johnson, N. L., Liou, J.-C und Matney, M. (2010): The Kessler Syndrome: Implications to Future Space operations. Advances in the Astronautical Sciences. 137. Therein: „There is little doubt that the result of the so-called 'Kessler Syndrome' is a significant source of future debris, as predicted over 30 years ago. Although new operational procedures have been developed over this period that have slowed the growth in orbital debris, these procedures have not been adequate to prevent growth in the debris population from random collisions."

[41] Nomura, K., Rella, S., Merritt, H., Baltussen, M., Bird, D., Tjuka, A., & Falk, D. (2024): Tipping Points of Space Debris in Low Earth Orbit. International Journal of the Commons, 18(1), pp. 17–31 (https://doi.org/10.5334/ijc.1275). A selection of more recent studies and articles: Drmola J., Hubik, T.: Kessler Syndrome: System Dynamics Model. Space Policy, Volumes 44–45, August 2018, Pages 29-39 (https://www.sciencedirect.com/science/article/abs/pii/S0265964617300966).

[42] Hudson, J. (2023). KESSYM: A stochastic orbital debris model for evaluation of Kessler Syndrome risks and mitigations. Journal of Student Research, 12(1). https://doi.org/10.47611/jsrhs.v12i1.4013
[43] Konkret wird auf die Modelle MASTER-8 der ESA und ORDEM der NASA Bezug genommen.
[44] See: https://phys.org/news/2024-06-satellite-megaconstellations-jeopardize-recovery-ozone.html.
[45] On a NASA webpage, one can see quite clearly how light pollution has increased over the past years. See: https://svs.gsfc.nasa.gov/30919.
[46] See: https://cosmosmagazine.com/weekly-edition/flagstaff-light-pollution/. In this article, astronomer James Lowenthal from Smith College, Massachusetts, is quoted as follows: „We astronomers are sort of the canary in the coal mine".
[47] Karska, J., Kowalski, S., Gładka, A. et al: Artificial light and neurodegeneration: does light pollution impact the development of Alzheimer's disease?. GeroScience 46, 87–97 (2024) (https://doi.org/10.1007/s11357-023-00932-0). This work summarizes the results of a variety of studies.
[48] A biological process in the body that recurs approximately every 24 hours and controls various physiological and behavioral changes such as the sleep-wake cycle. The Nobel Prize in Medicine was awarded in 2017 for demonstrating how this process is controlled by genes and hormones. See: https://www.dw.com/de/medizin-nobelpreis-f%C3%BCr-die-erforschung-der-inneren-uhr/a-40775026.
[49] This question is discussed for our old acquaintance, Scarabaeus satyrus, in this article in „The Conversation": https://theconversation.com/skyglow-forces-dung-beetles-in-the-city-to-abandon-the-milky-way-as-their-compass-165110.
[50] Raap, T., Pinxten, R. & Eens, M.: Light pollution disrupts sleep in free-living animals. Sci Rep 5, 13557 (2015). (https://doi.org/10.1038/srep13557).
[51] See: https://theconversation.com/the-surprising-reason-why-insects-circle-lights-at-night-they-lose-track-of-the-sky-221387.
[52] Avalon C.S. Owens, Précillia Cochard, Joanna Durrant, Bridgette Farnworth, Elizabeth K. Perkin, Brett Seymoure: Light pollution is a driver of insect declines. Biological Conservation, Volume 241, 2020, (https://doi.org/10.1016/j.biocon.2019.108259).
[53] See: https://theconversation.com/light-pollution-affects-coastal-ecosystems-too-this-underwater-canary-is-warning-of-the-impacts-226599. Therein: „Patterns in nocturnal illumination (known as artificial light at night, or ALAN) of surface waters have a surprisingly large impact on these fish. The prevalence of light pollution from cities (in this case New Zealand's capital Wellington) can potentially interfere with their breeding cycles."
[54] As mentioned, there is an immense variety of works on the topic. As a representative example, I would like to mention the following extensive meta-study: Gaston, K. J., Gardner, A. S., Cox, D. T. C: Anthropogenic changes to the nighttime environment. BioScience, Volume 73, Issue 4, April 2023, Pages 280–290 (https://doi.org/10.1093/biosci/biad017). On the following page, you'll find a wealth of scientific articles on the topic, listed under the links section: https://darksky.org/resources/what-is-light-pollution/effects/wildlife-ecosystems/.
[55] See: Crutzen, P.J. (2002): Geology of mankind. Nature Vol 415 (https://www.nature.com/articles/415023a).
[56] https://stratigraphy.org/
[57] See, for example: https://www.science.org/content/article/anthropocene-dead-long-live-anthropocene and: https://www.deutschlandfunk.de/entscheidung-expertenkommission-wir-leben-nicht-im-anthropozaen-dlf-7981bc76-100.html.
[58] See: https://darksky.org/about/our-strategy/.
[59] See: https://www.torrancebarrens.com/.
[60] See https://forestryandland.gov.scot/visit/forest-parks/galloway-forest-park und https://zselic.csillagpark.hu/.
[61] See: https://www.starlight2007.net/index_option_com_content_view_article_id_185_starlight-declaration_catid_62_the-initiative_itemid_80_lang_en.html.
[62] See: https://en.fundacionstarlight.org/.
[63] On the page „Portal to the Heritage of Astronomy" you can download a study: https://web.astronomicalheritage.net/index.php/thematic-study-1. Chapter 16 about „starlight, dark-sky areas and observatory sites" begins with the following sentences: „The sky, our common and universal heritage, is an integral part of the environment perceived by humanity. (…) Many different factors, but most notably the continued increase in light pollution, are turning this resource—virtually unchanged throughout the history of humankind—into an extremely scarce asset. An essential element of our civilisation and culture is rapidly becoming lost, and this loss is affecting most countries on Earth. Under these conditions, certain places whose sky is still dark, and whose scientific cultural or environmental values depend on starlight, should be recognized and preserved as points of reference to a common heritage in danger."

[64] See: https://darkskyparks.org/. Here, you find a list of „dark sky places“ across the globe: https://darkskyparks.org/dsag/2021-02-28_DSAG_word_list.htm.
[65] See: https://darksky.org/.
[66] See: https://twanight.org/.
[67] See: https://www.biosphaerenreservat-rhoen.de/natur/sternenpark-rhoen.
[68] See: https://www.nationalpark-eifel.de/de/nationalpark-erleben/sternenpark/.
[69] See: https://www.sternenpark-winklmoosalm.de/.
[70] See: https://www.westhavelland-naturpark.de/.
[71] See: https://www.sternenstadt-fulda.de/.
[72] See: https://www.sternenpark-schwaebische-alb.de/.
[73] See: https://www.naturpark-nossentiner-schwinzer-heide.de/.
[74] See: https://www.valleesdegavarnie.com/en/la-reserve-internationale-de-ciel-etoile-du-pic-du-midi/.
[75] See: https://www.francebleu.fr/infos/societe/strasbourg-va-eteindre-d-ici-un-an-la-moitie-de-son-eclairage-public-la-nuit-2989070.
[76] From the quote at the beginning of this text: Sagan, C. (1994): Pale Blue Dot: A Vision of the Human Future in Space. Ballantine Books, The Random House Publishing Group (Chapter 8).