# LIGHT POLLUTION IN CROATIA: A GROWING PROBLEM FOR ASTROPHOTOGRAPHERS

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***Abstract:*** *This paper explores the issue of light pollution in Croatia with a focus on its impact on astrophotography. Light pollution, defined as the alteration of natural light levels at night due to artificial sources, has been increasing globally by 7–10% annually. Croatian cities, particularly Zagreb, exhibit levels of light pollution comparable to major global metropolises, severely impacting the quality of astrophotography. The study identifies Croatia's darkest areas suitable for astrophotography (e.g., Lika, the islands of Lastovo and Vis, and Vrani Kamen), as well as those with the highest light pollution. It also examines current legislation and implementation challenges, including concrete violations of the Light Pollution Protection Act. Special attention is given to the potential of developing astrotourism as a sustainable economic activity. The paper proposes technological, regulatory, and educational measures to reduce light pollution, such as implementing lighting curfews, modernizing public lighting, and establishing dark-sky parks. Ultimately, the paper underscores the need for a systematic, collaborative approach involving the scientific community, local authorities, the tourism sector, and civic initiatives to preserve the night sky as a valuable natural and cultural resource.*

***Keywords:*** *astrophotography, space, ecology, light, tourism.*

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## 1. INTRODUCTION

### 1.1. Problem definition

Light pollution is a complex ecological phenomenon defined as the alteration of natural night-time light levels caused by artificial light emissions. According to the "Globe at Night" project by Christopher Kyba (GFZ Helmholtz-Zentrum für Geoforschung 2023), light pollution is increasing globally at an alarming annual rate of 7–10%, significantly surpassing satellite measurement estimates. This trend is global and Croatia is no exception.

The consequences of light pollution are multifaceted and well-documented. Disruption of natural ecosystems includes interference with bird migration patterns, disorientation of nesting sea turtles, and changes in reproductive cycles of various animal species. Health issues in humans linked to light pollution include circadian rhythm disturbances, reduced melatonin production, and potentially an increased risk of certain cancers, as noted by the Croatian Institute of Public Health.

Astrophotographers, who capture celestial objects, are particularly affected. Light pollution dramatically reduces the visibility of stars and celestial bodies, diminishes night sky contrast, and often completely prevents quality astronomical photography. As a result, astrophotographers are forced to travel to remote, often inaccessible locations, increasing the cost and time required to create high-quality images.

In Croatia, light pollution is most pronounced in urban areas. A scientific study published in the Rudarsko-geološko-naftni zbornik (Andreić 2018. - "Night sky brightness above Zagreb 2012–2017.") reports that sky brightness over Zagreb averages 16.9 magnitudes (mag/arc sec²), higher than that over Hong Kong and Vienna—despite Zagreb having a significantly smaller population.

Although Croatia implemented the Light Pollution Protection Act (NN 14/2019) in 2019, its enforcement remains weak. Lighting curfews are often ignored, decorative lighting is used in protected natural areas (e.g., the overly illuminated Pelješac Bridge in the Neum Bay Nature Park), and the ban on illuminated billboards at Zagreb intersections is regularly circumvented.

### 1.2. Aim and Purpose of the Study

The primary aim of this study is to systematically investigate and document the state of light pollution in Croatia and its impact on astrophotography. Specific objectives include:

- Identifying and analyzing the darkest locations in Croatia suitable for astrophotography
- Documenting areas with the highest levels of light pollution
- Investigating the causes and patterns of light pollution spread in Croatia
- Assessing the impact of light pollution on astrophotography quality
- Evaluating the potential for developing astrotourism as a sustainable economic activity

The paper aims to provide a scientifically grounded analysis of the problem while offering practical recommendations for its mitigation. Special attention is given to the potential of astrotourism, which according to Krajnović and Hordov (2021), "should remind us how little we know about the world we live in, and that a piece of heaven is so close to us every night."

The purpose of the paper is to contribute to the understanding of light pollution in the Croatian context, raise awareness of its impact on astrophotography and ecosystems, and encourage the implementation of current legislation and development of new strategies to preserve dark skies as a valuable natural resource.

### 1.3. Research Methodology

This paper employs a multidisciplinary approach including:

- Data analysis from relevant sources, primarily www.lightpollutionmap.info
- Field research and photographic documentation of various locations in Croatia
- Comparative analysis of light pollution in Croatian and European cities
- Review of scientific literature, especially articles in the *Rudarsko-geološko-naftni zbornik*
- Analysis of legal regulations, primarily the Light Pollution Protection Act (NN 14/2019)
- Assessment of astrotourism development potential based on existing practices such as workshops on Učka and night observations on Lastovo

The research combines quantitative data on light pollution intensity with qualitative assessment of its impact on astrophotography. Special attention is given to documenting inadequate lighting examples and their effects on the night sky using original field photographs.

The methodological approach enables a comprehensive analysis that connects scientific data on light pollution with the practical experiences of astrophotographers, thus creating a basis for informed recommendations and future dark sky preservation strategies in Croatia.

## 2. LIGHT POLLUTION: DEFINITION AND CAUSES

Light pollution refers to a complex ecological phenomenon involving the alteration of natural nighttime light levels caused by artificial sources. This phenomenon is not merely a byproduct of industrial civilization but is also the result of poor urban planning, unprofessional lighting solutions, and a lack of public awareness regarding its consequences. According to the Light Pollution Protection Act (NN 14/2019), light pollution is defined as "the alteration of natural light levels during nighttime caused by the emission of light from artificial sources which adversely affects human health, impairs traffic safety due to glare, directly or indirectly emits light toward the sky, disrupts the life and/or migration of birds, bats, insects, and other animals, disturbs plant growth, and compromises ecosystem balance, particularly threatening natural heritage."

Industrialized nations experience the highest levels of light pollution, where densely populated urban areas, intensive commercial activity, and poorly regulated lighting form so-called "light domes" above cities, visible from hundreds of kilometers away. This issue is worsening globally, as shown by the Globe at Night project (Kyba 2023), documenting an annual increase of 7–10% in light pollution worldwide.

### 2.1. Light Pollution in Croatia

According to detailed data from the Light Pollution Map (https://www.lightpollutionmap.info), Croatia experiences significant light pollution, especially in urban centers and along the coast. Zagreb, Split, and Rijeka are major hotspots of light pollution, forming domes of artificial light that extend into surrounding areas and severely degrade the quality of the night sky.

A particularly alarming study by Andreić et al. (2018), published in the Rudarsko-geološko-naftni zbornik, found that average sky brightness over Zagreb between January 2012 and December 2017 was 16.9 magnitudes (mag/arc sec$^2$) - worse than readings over Hong Kong and Vienna, despite Zagreb's smaller size.

The longitudinal nature of this study, which was conducted above the RGN Faculty building near the center of Zagreb, allows for monitoring the dynamics of light pollution over a longer period of time. The collected data show that the average brightness of the night sky during the analyzed period is approximately constant, with certain annual fluctuations that are primarily caused by changing meteorological conditions.

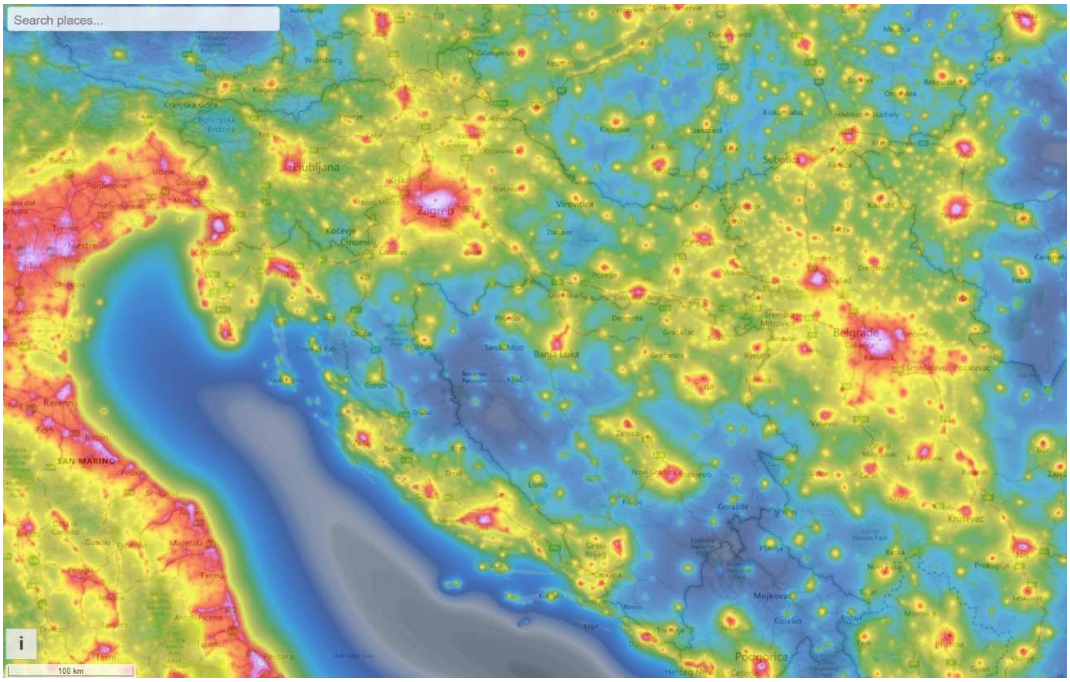


***Figure 1.*** *Light pollution map of Croatia (www.lightpollutionmap.info)*

***Figure 2.*** *Night panorama of Zagreb, taken from Samobor*

## 2.2. Legislation and Implementation

Croatia adopted a new Light Pollution Protection Act in 2019 (NN 14/2019), replacing the 2011 version. This law outlines planning, construction, maintenance, and retrofitting standards for lighting infrastructure, aiming to reduce artificial lighting's negative impact on the environment and human health. It includes mandates such as:

- A lighting curfew between 11 PM and 4 AM
- Prohibition of upward-facing lighting
- Mandatory use of environmentally friendly light fixtures

Despite a progressive legal framework, enforcement is weak. Light pollution continues to rise, consistent with global trends noted in the Globe at Night data. Violations are frequent, ranging from decorative lighting in nature parks to light-emitting billboards at intersections.

## 2.3. Documented Cases of Light Pollution

Croatia presents numerous examples of inappropriate lighting. One systemic issue is the excessive lighting on highway exits, which wastes energy and contributes to light pollution. By contrast, Hungary does not illuminate any of its highway exits.

Churches and cultural monuments are frequently over-lit. For instance, the church of St. Michael in the Istrian village of Šterna is so brightly lit that it endangers traffic safety at a nearby intersection. Such lighting not only violates legislation but also contradicts its intent by potentially harming citizens' well-being.

***Figure 3.*** *Light pollution in the small Istrian town of Šterna*

These examples show that despite the existence of legal regulations, there is still significant room for improving outdoor lighting management practices in Croatia, with the aim of reducing light pollution and its harmful consequences for the environment, human health and, specifically in the context of this work, conditions for astrophotography.

## 3. DARKEST LOCATIONS IN CROATIA SUITABLE FOR ASTROPHOTOGRAPHY

### 3.1. The Potential of Croatia's Dark Skies

Despite the widespread presence of light pollution, Croatia still has several locations that, according to international standards, fall within areas of minimal light pollution, providing ideal conditions for astrophotography. According to data available on the interactive Light Pollution Map, certain areas in Croatia still retain a dark sky quality of Class 1 and 2 on the Bortle Scale, making them exceptionally valuable natural resources.

However, the trend of increasing light pollution is also present in Croatia. The "Globe at Night" project (https://www.globeatnight.org/) documents a global annual increase in light pollution of 7–10%, a trend that is also reflected in Croatia. This alarming trend highlights the urgent need to preserve the remaining dark-sky areas.

### 3.2. Former and Lost Sites

A favorite destination for astrophotographers was Petrova Gora, but the potential Dark Sky Park in the area has been compromised by the construction of a transmitter. According to analyses published in the Mining-Geology-Petroleum Engineering Bulletin (https://doi.org/10.17794/rgn.2018.3.9), the Petrova Gora area recorded dark sky brightness levels above 21.0 mag/arc sec², placing it among the highest-quality locations for astronomical observation in continental Croatia. Unfortunately, recent infrastructure investments have degraded this natural resource.

### 3.3. Currently Viable Locations

- **Lika Region**: The triangle between Udbina, Gračac, and Donji Lapac is the darkest in Croatia (21.5–21.8 mag/arc sec²). Depopulation and sparse lighting infrastructure preserve this darkness.

- **Lastovo Island**: Distant from the mainland, Lastovo reaches 21.7 mag/arc sec² and has the potential to be recognized as an International Dark Sky Park.
- **Vis Island**: Due to its isolation and small population, Vis maintains values around 21.6 mag/arc sec², ideal for observing the Milky Way and deep sky objects.
- **Vrani Kamen (Papuk)**: Offers dark skies around 21.3 mag/arc sec² due to altitude and remoteness.

***Figure 4.*** *Autumn panorama of the Milky Way near Bunić, Lika*


***Figure 5.*** *Summer nights on Lastovo, in the bay of Skrivena luka*

## 4. LOCATIONS WITH THE WORST LIGHT POLLUTION

### 4.1. Zagreb

Zagreb's light pollution levels (16.9 mag/arc sec²) are comparable to larger European cities. This impairs the visibility of the Milky Way and dim celestial objects.

### 4.2. Split and Rijeka

Both cities generate light domes extending across adjacent coastal areas and islands, diminishing their potential for astrotourism.

### 4.3. Decorative Lighting Issues

Excessively illuminated cultural landmarks, such as Trakošćan Castle, often violate legal provisions by remaining lit overnight with upward-facing light. This also leads to unnecessary $CO_2$ emissions.

### 4.4. Comparison to EU Standards

When comparing the situation in Croatia with European standards, it is evident that Croatia is lagging behind in implementing measures to reduce light pollution. According to the "Globe at Night" project (https://www.globeatnight.org/), while countries such as Slovenia and Italy are enforcing strict regulations on outdoor lighting, Croatia still lacks consistent enforcement of existing regulations, leading to continued degradation of night sky quality.

***Figure 6.*** *Unnecessarily bright decorative lighting at Trakošćan Castle, February 2023*

## 5. ASTROTOURISM IN CROATIA

### 5.1. Definition and Potential

Astrotourism represents a specific branch of selective tourism that involves observing the night sky, learning about astronomy, and participating in scientific activities related to astronomy. Croatia possesses exceptional potential for developing this growing tourism niche, particularly in areas with minimal light pollution such as Lika, the islands of Lastovo and Vis, and the location of Vrani kamen. According to Krajnović and Hordov (2021), astrotourism, as a distinct form of tourism, has been experiencing significant global growth, and Croatia, with its natural and geographical features, can become a competitive destination in the European astrotourism market (https://hrcak.srce.hr/).

Astrotourism should serve as a reminder of how little we know about the world we live in, and that every night a ‘piece of heaven’ is so close—we just need to look up from time to time instead of constantly keeping our heads down, burdened by everyday stress (https://hrcak.srce.hr/). This philosophical dimension of astrotourism further expands its significance beyond the traditional tourism offer, connecting it with education, self-awareness, and sustainable development.

***Figure 7.*** *It is enough to turn off the decorative lighting while everyone is sleeping, and the location becomes perfect for astrophotography and astrotourism - Trakošćan, October 2024*

### 5.2. Impact of Light Pollution

Light pollution is a major obstacle to the development of astrotourism and high-quality astrophotography. According to data from the "Globe at Night" project (Kyba 2023), light pollution is increasing at an annual rate of 7–10%, which significantly exceeds estimates obtained through satellite measurements (https://www.globeatnight.org/). This increase has a direct negative impact on the ability to observe the night sky.

For astrophotographers, light pollution causes multiple problems:

- It makes it difficult or entirely impossible to capture faint celestial objects
- It significantly reduces contrast and detail in photographs
- It increases the need for complex post-production and image processing
- It forces photographers to travel to remote locations, increasing costs and requiring additional time and resources

An analysis of light pollution over Zagreb, published in the Mining-Geology-Petroleum Engineering Bulletin, shows that the average night sky brightness in Zagreb is 16.9 magnitudes, which is higher than the light pollution levels recorded over Hong Kong and Vienna (https://doi.org/10.17794/rgn.2018.3.9). This level of pollution effectively prevents high-quality astrophotography and astrotourism activities near major urban centers.

### 5.3. Potential Locations and Infrastructure for the Development of Astrotourism

If decorative and unnecessary lighting were reduced or completely turned off in accordance with the Law on the Protection Against Light Pollution (Official Gazette 14/2019), many locations in Croatia could become internationally recognized astrotourism destinations. Notable examples include:

- Trakošćan: With appropriate lighting management, this historic complex could combine cultural heritage with astrotourism.
- Plitvice Lakes: A national park with potential for the development of special night tours for stargazing.
- Lonjsko Polje: A protected wetland area with minimal light pollution.
- Istrian Desert: A unique ecosystem well-suited for nighttime sky observation.

The Croatian Institute of Public Health warns that the interaction of artificial light with the human body can have potentially harmful effects on health, further emphasizing the importance of preserving dark skies—not only for tourism and science, but also for public health (https://www.hzjz.hr/).

### 5.4. Strategic Guidelines

Recommendations include:

- Educational programs, observatories, and telescope installations
- Partnering with hotels for stargazing packages
- Dark Sky Park certification processes


***Figure 8.*** *Astroworkshop for students of UD Podmurvice from Rijeka, near the Vojak Tower on top of Učka*

### 5.5. Economic Benefits

Given the growing interest in astrotourism in Europe, Croatia has the potential to significantly diversify its tourism offerings and extend the tourist season. According to a study by Krajnović and Hordov (2021), astrotourism attracts higher-spending visitors, extends the tourism season, and stimulates the development of local communities (https://hrcak.srce.hr/).

The portal Zastita-prirode.hr states that reducing light pollution can also lead to significant economic savings through reduced electricity consumption, which could further encourage local communities to implement light pollution reduction measures (https://www.zastita-prirode.hr/).

The Croatian Astronomical Society, through its platform Astronomija.hr, regularly organizes educational activities that could serve as a model for broader astrotourism initiatives (https://www.astronomija.hr/). Their model of organizing workshops and educational programs could be expanded to the national level as part of a strategic astrotourism development initiative.

Timely recognition of the potential of astrotourism and the implementation of appropriate light pollution reduction measures would enable Croatia to preserve its dark-sky natural resources while developing a sustainable and innovative tourism offer that attracts visitors year-round, particularly in the pre- and post-season periods.

## 6. MEASURES FOR REDUCING LIGHT POLLUTION

### 6.1. Technological Measures

- **Eco-friendly lighting**: LED lights with a color temperature below 3000K
- **Directional lighting:** Fully shielded fixtures directed only at intended surfaces
- **Motion sensors:** Reduce unnecessary light emissions

### 6.2. Regulatory Measures

- **Lighting curfew (11 PM–4 AM):** Especially for decorative and non-essential lighting
- **Zoning:** Define lighting intensity limits by region (E0–E4 zones)

***Figure 9.*** *Brinje, Sokolac Castle – top photo, January 2024 / bottom photo, July 2022*

### 6.3. Educational Initiatives

- School programs, expert workshops, and public exhibitions on light pollution

### 6.4. Best Practices

- **Lastovo:** A model for controlled outdoor lighting
- **Flagstaff, Arizona**: Pioneer in comprehensive lighting regulation
- **Slovenia**: First nation with national light pollution law
- **La Palma, Spain:** Home to a major observatory with strict light control

## 7. CONCLUSION

Light pollution represents a multifaceted problem that goes beyond hindering astrophotography – it is an ecological, health, energy, and cultural challenge. The conducted research clearly shows that Croatia is experiencing alarming levels of light pollution in urban centers, with cities like Zagreb reaching levels comparable to much larger European metropolises. At the same time, Croatia possesses extremely valuable resources in the form of areas with minimal light pollution – especially Lika, the islands of Lastovo and Vis, and the Vrani Kamen location – which serve not only as refuges for astrophotographers but also as significant potential for the development of sustainable astrotourism.

A legal framework for addressing light pollution has existed in Croatia since 2019, through the Law on the Protection Against Light Pollution, but its implementation remains insufficient. Documented cases of excessive lighting of cultural landmarks, such as Trakošćan Castle and the Church of St. Michael in Šterna, as well as unnecessary lighting of highway ramps, clearly indicate a disregard for existing regulations and a lack of

awareness regarding the importance of preserving dark skies.

Experiences from 2022, when some cities and municipalities temporarily introduced light curfews from 11 PM to 4 AM due to rising electricity prices, demonstrate that implementing light pollution reduction measures is not only ecologically justified but also economically viable. Reducing unnecessary lighting during late-night hours could yield significant energy savings – according to expert estimates, modernizing lighting could reduce carbon dioxide emissions by as much as 40 tons annually per lighting fixture.

Alongside the ecological and economic benefits, health aspects must not be overlooked. Scientific studies confirm that artificial light sources contain wavelength components that pose potential risks to human health, affecting circadian rhythms and hormonal balance. Long-term exposure to unnatural light levels during the night is associated with an increased risk of various health issues.

Taking all of the above into account, we propose the following specific measures:

- Consistent enforcement of the existing Law on the Protection Against Light Pollution through the formation of specialized inspection teams
- Establishment of at least one officially certified "dark sky park" in the Lika region or on the island of Lastovo
- Development of a national astrotourism strategy that would connect existing initiatives (such as workshops on Mount Učka) and encourage new projects
- Modernization of public lighting by replacing outdated fixtures with energy-efficient LED lights with directed beams
- Introduction of a mandatory "light curfew" between 11 PM and 4 AM for decorative and non-functional lighting in all Croatian cities and municipalities

By implementing these measures, Croatia would not only reduce light pollution and its negative consequences but could also become a recognized destination for dark-sky enthusiasts and astrophotographers from across Europe. Astrotourism, as a growing segment of sustainable tourism, offers a unique opportunity for the economic valorization of a natural resource that we still possess but are rapidly losing.

Preserving the dark sky is not a nostalgic return to the past, but an investment in a healthier, more energy-efficient, and aesthetically richer future. Through joint efforts of the scientific community, local and national governments, the tourism sector, and civic initiatives, we can create a sustainable model that reconciles the needs of modern society with the preservation of one of humanity's oldest experiences – gazing at the starry sky.

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