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The Gaia4Sustainability project

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Abstract

Gaia4Sustainability (https://gaia4sustainability.eu) is a Proof-of-Concept project granted by the MICINN in the 2021 call. It develops a robust, reliable, and straightforward framework to assess the brightness of the night sky. It consists of a set of implementations (web service, stand-alone program and open-source measurement device) devised for any interested stakeholder to accurately evaluate light pollution. High quality photometry provided by the ESA Gaia satellite allows the computation of the contribution of the integrated star light to the sky brightness.

To obtain reliable measurements of the light pollution, it is mandatory to know the natural night sky brightness. We use GAMBONS, a model of the natural sky brightness, to get a realistic image of the night sky for a given place and time that can be used as a reference value. Furthermore, Gaia4Sustainability includes the design and construction of a cheap and easy-to-build photometer, named FreeDSm. It is based on an ESP32 microcontroller, which integrates different sensors. This twofold methodology (modelling and low-cost measuring) proposed by Gaia4Sustainability, intends contributing to 1) widely spread the acquisition of standardised measurements; 2) achieve a greater engagement of social agents; and 3) raise generalised awareness on the light pollution problem.

1 Introduction

Light Pollution affects not only the observing night sky conditions. The use of Artificial Light at Night (ALAN) is now an irreplaceable technology for our society. But the use of inappropriate illumination generates an environmental problem, the light pollution. Among modern environmental problems light pollution, understood as the alteration of the natural brightness of the sky due to artificial light sources, is the one that has increased most in recent times. Although its effects are most notorious in highly populated areas and developed countries, it is beyond doubt a very serious worldwide problem: nowadays, at least 60% of the Earth's population lives under light polluted skies and in Europe and the USA the fraction increases up to more than 80%. Despite the increasing social awareness, the efforts of the scientific community and the citizens' actions to mitigate the problem, light pollution is still increasing at a yearly basis rate of 2%.

Dark Sky for Sustainability with Gaia (Gaia4Sustainability) is a Proof-of-Concept project (https://gaia4sustainability.eu, see Fig. 1) coordinated between the Universitat de Barcelona and the Universidade da Coruña. The objective of the project is to provide a robust, reliable and easy-to-use framework for estimating the natural night sky brightness, and accurately evaluating the impact of light pollution level. The Gaia4Sustainabiliy framework allows to compute the excess of sky brightness with respect to the natural sky brightness and, therefore, provide a realistic light pollution measure in a way that is more understandable and usable by the general public and/or non-scientific stakeholders than the usual values used by the scientific community.

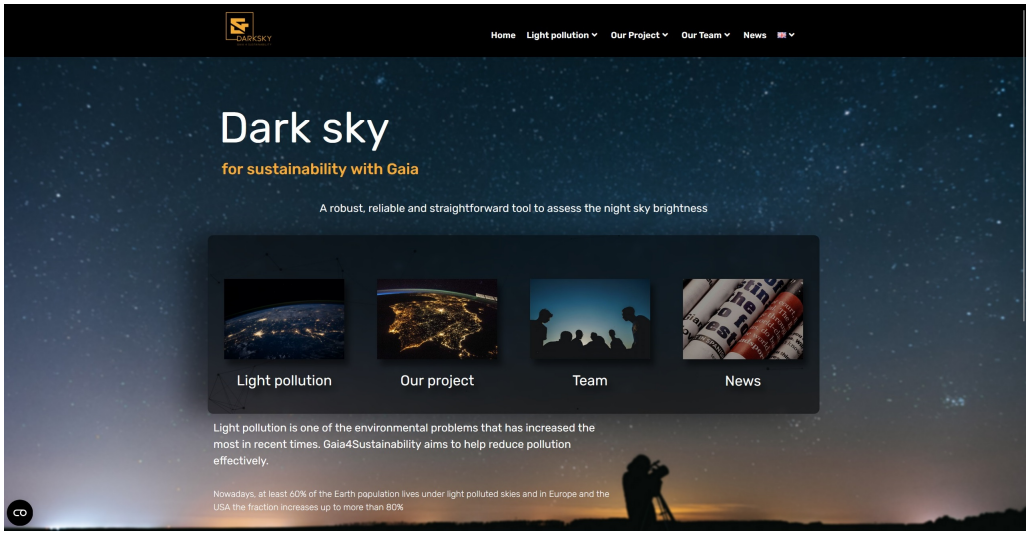

Figure 1: Gaia4Sustainability web portal

2 Measuring the light pollution with Gaia4Sustainability

Measuring light pollution can be done using different methods and instruments. Photometers such as the Sky Quality Meter (SQM) and TESS are popular for quantifying the brightness of the night sky. This type of photometers provides a simple and accurate way to assess light pollution levels and can be used for continuous monitoring. Another method involves the use of all-sky cameras, which capture wide-angle images of the night sky. These cameras can be used to analyze the distribution and intensity of artificial light, providing a comprehensive view of the light pollution over a larger area.

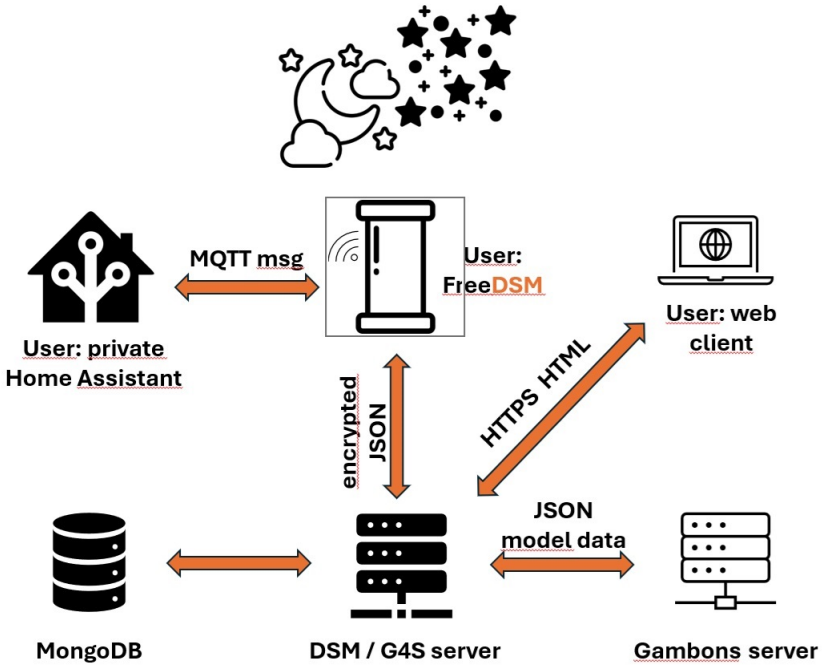

Figure 2: Gaia4Sustainability operational scheme

Whatever method we use to measure the brightness of the sky, what we are actually measuring is the sum of the natural brightness plus the light pollution. But the natural sky brightness is not constant over time. The presence or absence of the Milky Way, or the height of the zodiacal light above the horizon, introduce non-negligible variations (more than 0.5 mag arcsec^{-2}) on the night sky brightness. On the other hand, the atmosphere conditions, especially the ones related with the atmospheric extinction (directly linked to the amount of aerosols present in the atmosphere) introduce variability in the sky brightness. Also the airglow, a faint emission of light caused by various processes in the upper atmosphere that can contribute more than 50% to the night sky brightness, is highly variable on time scales that range from hours to years. So, an essential requirement to obtain reliable measurements of the light pollution levels at a given place is to know the value of its natural sky brightness. In other words, we need a reference value that takes into account the natural contributions

and its variability, to compare with the measurements.

To overcome this drawback, Gaia4Sustainability proposes a framework that includes a sky brightness measuring device (FreeDSM, Free Dark Sky Meter, [1]) and the use of a natural night sky brightness model. Each measurement from the device is compared with the natural brightness value provided by the model (GAMBONS, [2, 3]), for the same location, time, and atmospheric conditions (if available) as the measurement. In this way Gaia4Sustainability provides the excess of brightness related to the natural brightness level, i.e. the light pollution. The operational scheme is shown in Figure 2.

3 FreeDSM photometer

FreeDSM ([1]) is an IoT photometer for citizen light pollution monitoring, developed in the context of the Gaia4Sustainability project (Figure 3). It is based on an ESP32 microcontroller, which is a cheap and low-consumption component that integrates different sensors. The ESP32 is powered by Tasmota, a well-known open IoT firmware that integrates basic logic for many commercial sensors. In the design, it is included a rechargeable battery, which allows different device use ways: fixed installation or portable use. We had developed a low cost, easy to handle, open software and hardware solution with the aim to empower individuals to take action to reduce unnecessary outdoor lighting, spread the word on night sky protection and popularise the access to astronomy at the same time.

Unlike other commercial photometers, the FreeDSM is an open software and hardware project. FreeDSM can be assembled using common electronic components, and the instructions for building it are available online. This makes it more accessible to astronomy enthusiasts and those interested in measuring light pollution without investing in expensive commercial devices. It is equipped with a PMMA lens, UV stable and with very good weather resistance, and a field of view (FOV) of around 40 degrees. Under it, an Osram TSL2591 sensor is installed, which contains infrared and full spectrum diodes, allowing separate measurements to be obtained. Additionally, it also integrates an AHT2x sensor that provides temperature and humidity measurements. All of this is encapsulated in a waterproof PVC casing when installed vertically. This casing has a small colour OLED screen and a joystick on the bottom to allow access and management via Wi-Fi using any web browser.

Furthermore, the device undergoes calibration using parallel measurements from commercial instruments and following a data-driven approach. Artificial Neural Networks and gradient descent techniques were used to fine-tune the coefficients for calculating magnitudes per square arcsecond (MPSAS), fixed in the open source C and microPython available libraries. The data collected by FreeDSM devices is processed through a centralized system (`https://g4s.citic.udc.es/`) that consolidates information from multiple devices to ensure comprehensive coverage and high accuracy. Additionally, FreeDSM can send the information to IoT home automation platforms, such as Home Assistant, and provides a debug mode with data transmission via http in standardized formats such as JSON. These three functionalities for transmitting measured data can operate simultaneously.

Figure 3: The FreeDSM photometer

4 The night sky model

Gaia4Sustainability uses GAMBONS (GAia Map of the Brightness Of the Natural Sky) model ([2, 3]) to determine the natural brightness (i.e. non polluted) of the night sky. In GAMBONS, this natural brightness is determined by the sum of the spectral radiances coming from astrophysical sources, including zodiacal light, and the atmospheric airglow. The resulting radiance is modified by absorption and scattering of the Earth's atmosphere before it reaches the observer. Therefore, the natural night sky brightness is a function of the location, time and atmospheric conditions.

GAMBONS is based on the extra-atmospheric star radiance obtained from the Gaia catalogue. The Gaia-DR3 archive compiles astrometric and photometric information for more than 1.7 billion stars up to $G = 21$ magnitude. For the brightest stars, not included in Gaia-DR3, GAMBONS uses the Hipparcos catalogue instead. After adding up to the star radiance the contributions of the diffuse galactic and extragalactic light, zodiacal light and airglow, and taking into account the effects of atmospheric attenuation and scattering, the radiance detected by ground-based observers can be estimated. This methodology can be applied to any photometric band, including the FreeDSM band, if appropriate transformations from the Gaia bands are available.

5 Conclusions

Gaia4Sustainability is a Proof-of-Concept project based in a twofold methodology (modelling and low-cost photometer) to measure the light pollution. The model provides a reference value to compare with the measurements, needed to account for the variability of the natural night sky brightness. GAMBONS, the model used by Gaia4Sustainability, integrates the radiance of the stars in the Gaia and Hipparcos catalogues to obtain the Integrated Star Light.

The cheap and easy procedure to build and use FreeDSM photometer and its comparison with the GAMBONS models developed in this work, makes this project easily exportable

to citizen science projects (at high school institutes, other universities, astronomical groups, ...). For example, FreeDSM has already been used in research projects in high schools helping to assess the light pollution present in areas around Barcelona city (see Fig. 4).

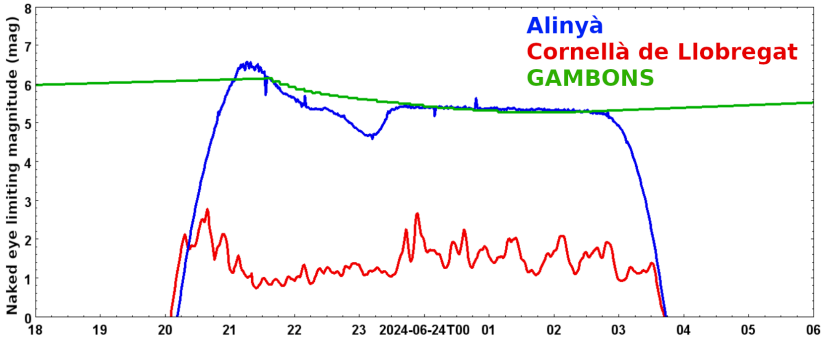

Figure 4: Naked eye limiting magnitude derived with FreeDSM in a citizen science project at "Joan Miró" high-school institute at Cornellà de Llobregat (Barcelona) compared with a less light polluted region (Alinyà, Lleida).

We expect that our set of tools will become instrumental to reduce light pollution and will help in increasing awareness of its harmful consequences. The project also contributes to spreading clear and verified information to the scientific community and to society in general, in the form of open data and open software and hardware.

Acknowledgments

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