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The UrbObsBel PROJECT: INSTRUMENTS AND DETECTORS

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Abstract. Urban Observatory of Belgrade (UrbObsBel) is a project hosted by Astronomical Observatory of Belgrade. Our main aim is to study, applying well-tested astronomical techniques, light pollution and dynamical processes of the Serbian capital, Belgrade. Our observations will provide valuable information on energy usage distribution that has a high impact on the environment and ecosystems. We have already mounted and we are also planning to mount several observational instruments covering spectral range from visible (400 nm) to infrared (13 micron), and use both broadband and hyperspectral imaging systems in our synoptic study. Apart from study of the urban dynamics we intend to use several instruments aimed at the study of sky brightness and various sources of sky pollution such as street lights. This would be achieved mounting identical instruments at Astronomical Observatory of Belgrade (AOB) and at our Astronomical Station at Vidojevica (ASV). Until now we have acquired the following equipment: Web and file server, TESS-W photometer, Unihedron Sky Quality Meter, Hyperspectral Imaging (HSI) devices, FLIR and AllSky Cameras.

1. INTRODUCTION

The main task of Urban Observatory of Belgrade (UrbObsBel) project was to mount a suite of imaging systems at the roof of the Tower at Astronomical Observatory of Belgrade (AOB) which is the highest point in the urban part of Serbias capital, Belgrade. Using this excellent position, we plan to measure as many observables as possible relevant for modern urban life and analyze them. Such a synoptic view of the city will provide the possibility to observe the city on various temporal scales, ranging from minutes to months and years. Our location provides a possibility to observe not only the urban zone (center of Belgrade), but also its surroundings, the forests and the river Danube, see Figure 1. You can find much more about the UrbObsBel project in the article Pavlović et al. (2025) or on the website `https://urbobsbel.aob.rs`. The UrbObsBel project started in January 2024 and will last for 3 years.

2. INSTRUMENTS AND DETECTORS

The UrbObsBel project began with the procurement of essential instruments for monitoring and studying light pollution (LP) in Belgrade. The instruments are:

- FLIR A700 cameras for thermal imaging,

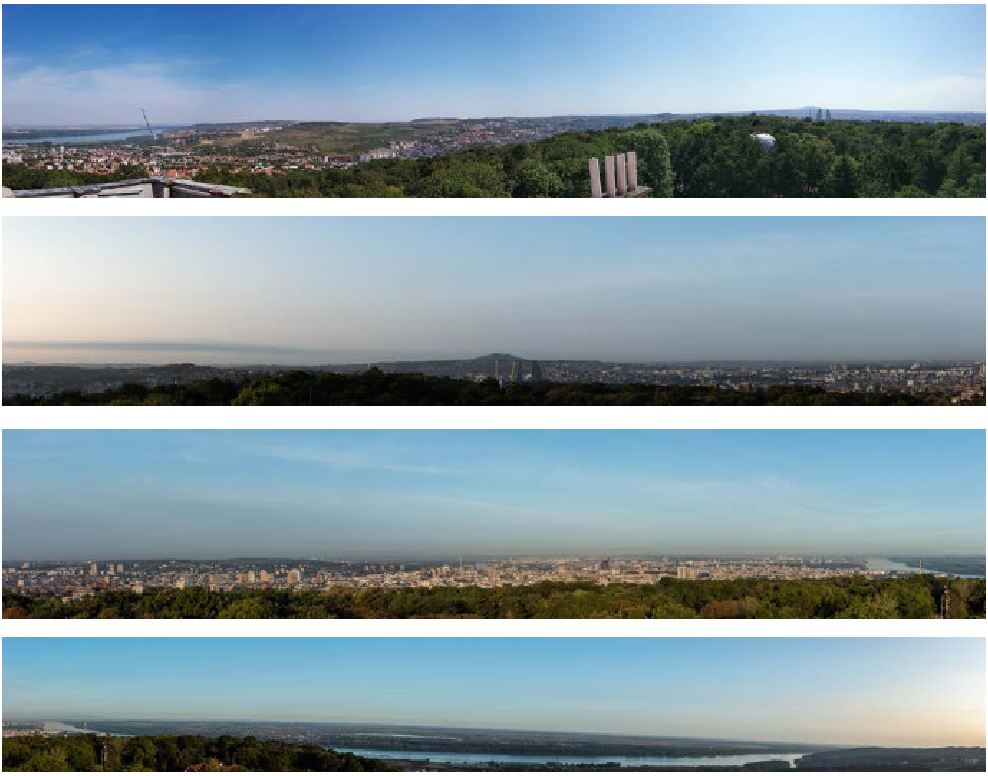

Figure 1: Panoramic view of Belgrade as seen from the top of the AOB Tower. From top to bottom: East, South, West, North. In the panel centered on the South the mountain Avala (elevation 511 m, located 16 km of downtown Belgrade) with the Tower overlooking Belgrade is visible and, in the panels, centered on the East, West and North one can see the river Danube.

- All-sky Camera for comprehensive sky monitoring,
- Sky Quality Meters (SQM) to measure night sky brightness,
- TESS-W Photometers (Telescope Encoder and Sky Sensor with WiFi) for sky condition monitoring,
- VNIR Hyperspectral Imaging Sensors (HSIs) to capture visible and near-infrared spectral data,
- Digital single-lens reflex (DSLR) camera with a fisheye lens and camera mount for panoramic imaging.

These instruments will be housed in a specially constructed, weather-resistant cover, allowing them to operate year-round and provide robust data on LP and environmental dynamics in Belgrades urban setting. Remote sensing will be integral to this approach. Additionally, one SQM and one TESS-W photometer were installed at the Astronomical Station Vidojevica for LP-free sky comparisons.

Figure 2: FLIR camera A700 (left) and All Sky camera Alcor OMEA 3C (right).

To support data storage and analysis, we acquired a dedicated data management server. The new server was located within our ready-to-use server cage at the Astronomical Observatory. Observational data will be archived in the FITS format, widely used in astronomy, and data cubes will be made publicly available upon acquisition.

Data analysis will employ techniques such as image processing, machine learning, computer vision, and specialized astronomical analysis, including Principal Component Analysis (PCA) as demonstrated by Dobler et al. (2021). Satellite data, including SENTINEL[1], GOES[2], and AQUA[3], will complement the projects ground-based observations, offering a broad perspective on LP and environmental dynamics across various scales.

Teledyne **FLIR A700**[4] infrared camera (Figure 2, left) offer researchers and engineers a streamlined solution for accurate temperature measurement. It has IR resolution 640×480 pixels, detector pitch 12 μm, spectral range from 7.5 to 14.0 μm and temperature sensitivity of $\pm 2^{\circ}$. We will also utilize two FLIR broadband infrared cameras simultaneously, positioning one toward the urban area and the other toward the surrounding areas of Belgrade, which are primarily covered with trees and grass. This setup will allow us to investigate the influences of factors such as weather, public holidays, major events, and construction sites within the spectral range of cameras.

All Sky Camera Alcor OMEA 3C[5] (Figure 2, right) is intended to monitor the entire sky in day and night conditions in a continuous manner. It is possible to assess, in real time, the night sky quality and record fast phenomena such as meteors and fireballs or slower ones such as artificial satellites, rockets, noctilucent clouds, airglow. This camera has a detector resolution of 3100×2100 pixels, $180^{\circ} \times 180^{\circ}$ field of view and pixel scale of 5.4 arcmin/pixel. For addressing the important issue of clouds, we plan to also use the wide-angle all-sky cameras (one is already installed at Vidojevica) and the latest machine learning algorithms (e.g., Mommert 2020) for estimates of the cloud coverage at any given time. It was shown that cloud coverage not only "dramatically amplifies the sky luminance" in urban areas (Kyba et al. 2011), but might also highly affect rural areas as well (Jechow et al. 2019).

[1] https://www.sentinel-hub.com
[2] https://web.archive.org/web/20050905030322/http://www.oso.noaa.gov/goes/index.htm
[3] https://aqua.nasa.gov/
[4] https://www.flir.eu
[5] https://www.alcor-system.com/new/AllSky/Omea_camera.html

Figure 3: Sky Quality Meters (top left), TESS-W Photometers (bottom left) and both instruments mounted at Astronomical Station Vidojevica (right).

We will use the **SQM and TESS-W photometers** (Figure 3) both in Belgrade and at the Astronomical Station Vidojevica for measuring the sky brightness, serving as a proxy for LP. The TESS-W is a newer instrument which is more extended to the red range and is able to estimate the cloud coverage at the same time together with the sky brightness. It sends the measurements to the STARS4ALL infrastructure thus placing both our observing stations in a broader context.

We built two **visible and near-infrared (VNIR) hyperspectral imaging (HSI)** (Figure 4) sensors as instructed by Salazar-Vasquez & Mendez-Vasquez (2020). Two such instruments (at only 2% of the cost of the commercially available HSIs) will also be directed to the urban area of Belgrade and its surroundings and will enable

Figure 4: Visible and near-infrared (VNIR) hyperspectral imaging (HSI) sensors.

us to perform, again simultaneously, remote sensing from 400 nm to 1052 nm in up to 315 wavebands. Both instruments will allow us to follow both short and long term changes in the urban dynamics through, for example, studying urban lighting as a proxy for environmental impact and as a measure of urbanization dynamics (Dobler et al. 2021).

Finally, a **DSLR camera** is in the process of being procured.

3. DATA USAGE

The UrbObsBel project will generate observational data obtained using the aforementioned instruments. We will use these measurements together with the data coming from various satellites mentioned above. All the data that will be obtained by us will be stored on our server and will be publicly available. The costs of data curation and preservation will be covered by the AOB.

Data Repository (DR) is going to be set up in the second project year and will provide access to all our measurements. The data server is going to be set up at the AOB and used for the storage of the data acquired, with scrupulous measures to be taken regarding access and data security. Accessibility of the DR through an adequate interface on the website will be provided at the end of realization of UrbObsBel and for five years after projects' ending. Clearly organized data for easy parsing and adequate employment of the scientific foreground is the priority. We will integrate our database into internationally available databases. We will use our observations for detailed analysis and we will rely on the available approaches such as in Kyba et al. (2011), Babari et al. (2011), Jechow, et al. (2017, 2019).

4. VERY FIRST RESULT

To analyze changes in the sky brightness in the urban area (AOB) and in the rural part of Serbia (ASV) we used two TESS-W devices mounted in these two locations. The first measurements of the TESS-W device during several nights in September 2024 are shown in Figure 5. By analyzing the data, we get $\mathrm{mag}_{\mathrm{AOB}} = 16.35$ for the brightness of the sky in Belgrade, while in Vidojevica it is $\mathrm{mag}_{\mathrm{AOB}}$ =21.16. Therefore, on ASV we can see fainter objects up to 4.5 mag than on AOB, and the reason is clear – light pollution.

5. INSTEAD OF A CONCLUSION

Gaining a deeper perspective on urban dynamics will enhance our understanding of light pollution (LP) and environmental pollution more broadly. Investigating artificial light at night (ALAN) is crucial for grasping the complexity of modern cities. As Sanchez de Miguel et al. (2022) noted, studying ALANs biological risks requires remotely sensed data on the spatial and temporal variation in the spectral composition of ALANa goal we aim to achieve with our planned observations.

To comprehensively understand urban behavior, it is essential to consider the three main factors shaping life in a large city like Belgrade: its people, natural environment, and infrastructure. We are excited to use advanced instruments to conduct Serbia's first in-depth analysis of these urban factors. With our exceptional vantage point on the roof of the Belgrade Observatory Tower, we are well-positioned to carry out

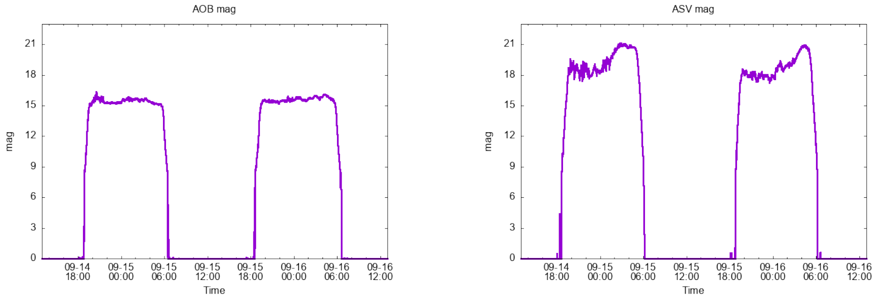

Figure 5: TESS-W measurements at Astronomical Observatory in Belgrade (left) and TESS-W measurements at Astronomical Station Vidojevica (right) during several nights in September 2024.

this pioneering study. We anticipate that our findings will offer valuable insights into urban dynamics and allow meaningful comparisons with similar studies across Europe and beyond.

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