

DIY photometer for night sky brightness in earth & space laboratory

Cahyo Puji Asmoro

Earth and Space Laboratory, Universitas Pendidikan Indonesia, Indonesia
Email: cp.asmoro@upi.edu

Hana Susanti

Physics Education Study Program, Universitas Pendidikan Indonesia, Indonesia
Email: hanasusanti@upi.edu

Judhistira Aria Utama

Earth and Space Laboratory, Physics Study Program, Universitas Pendidikan Indonesia, Indonesia
Email: j.aria.utama@upi.edu

Abstract. A photometer is a tool that can be used as a medium for learning, practicum, and research to study the quality of the night sky in Astrophysics courses. The photometry practicum provides work principles, tool settings, and data collection knowledge. Currently, the Earth and Space Laboratory of the Department of Physics Education has only one photometer. When used, it must be connected to a computer because there is no internal power, and it can not store data. This resulted in the photometry practicum failing to run optimally. Therefore, it is necessary to have the right solution to maintain the essence of practicum as the basis of knowledge, namely, to make your photometer called Do It Yourself (DIY). The method used in this study is an experimental method with data collection. Starting with a needs analysis, then the design of the photometer is carried out. This was followed by making a photometer and conducting a limited trial by measuring the Night Sky Brightness (NSB). The results showed that DIY Photometer functionally could measure the quality of the night sky. Also can show the same pattern as the measurement results using the manufacturer's SQM-LU so that the DIY Photometer that has been made can be used in photometry practicum activities in Astrophysics courses or other similar subjects.

Keywords: photometer, sky quality meter, night sky brightness

I. Introduction

In the Astrophysics lecture at the Department of Physics Education, one of the materials studied is about photometry, which is the science of measuring light in conditions that can be captured by the perception of the human eye in the form of intensity and brightness. In photometry, the level of light radiation is measured based on the human brightness sensitivity, known as Night Sky Brightness (NSB).

The sky's brightness varies greatly throughout the day, and the main causes are also different. During the day, when the sun is above the horizon, direct scattering of sunlight is the dominant light source. When the sun is below the horizon, i.e., after sunset or before sunrise, the situation is more complicated, and further differentiation is needed. The fact that the sky is somewhat dark at night is easy to see. Only direct starlight would be visible if light sources such as the moon and pollution were removed from the night sky.

In general, the results of photometric observations of astronomical objects are in the form of flux received by an observer on Earth, and flux is the amount of energy that passes through the unit surface element in all directions [1]. In astronomy, the unit of magnitude is often used instead of the basic measurement of the quantity in energy or photon flux [2]. Magnitude is a dimensionless quantity and is related to flux, and flux (F) can be converted to magnitude (m) using Pogson's equation (1).

$$m = 2.5 \log F_0 - 2.5 \log F \quad (1)$$

Where F_0 is the proportionality coefficient, namely the flux when the magnitude value is 0.0; the quantity $2.5 \log F_0$ is referred to as the photometric system's zero point (ZP).

One of the photometers on the market is the Sky Quality Meter (SQM), see figure 1, the photometer is used to measure the night sky's brightness (NSB) in the form of magnitude per square arc second or mathematically. It can be written $\text{mag}/\text{arcsec}^2$ (mpsas) with the measurement angle 20° to the sky. This tool works based on a silicon photodiode type light sensor (ams-TAOS TSL237S) which can capture light from the sky and convert it into an electronic signal in the form of frequency after passing through the HOYA CM-500 filter, which works to filter infrared wavelengths, providing a final spectral response that in line with Johnson's B and V bands used in astronomical photometry [3].

SQM (Figure 1) can also be used to determine the light pollution of a place [4], [5], the initial interaction of the solar eclipse [6]–[8], and the determination of twilight time [4], [9]. SQM is a tool used to measure the luminance of the night sky with pocket size. This tool makes it possible for the general public to measure the quality of the night sky anytime and anywhere [10].



Figure 1. Sky Quality Meter Unihedron-LU [11]

Since the Covid-19 pandemic hit the Indonesian state, it has had a domino effect on every line of life. One of them is in the field of education, and the learning process is carried out online or remotely using information technology, either using Whatsapp Groups or video conferences such as Zoom or Google Meet. Likewise, the practicum process becomes hampered, even just watching through video introductions of tools or virtual tools, which are quite limited.

The practicum process, which is usually hands-on to train students' analytical and process skills, needs to be improved. One of them is the Photometry Practicum in the Astrophysics course. The limited number of photometers, only one unit in the Earth Space Laboratory, also hampers practicum activities. The existing photometer types still have to be connected to a computer device to be used because there is no power and an internal data storage system in the photometer system. In addition, the price of photometers which is still quite high is also a challenge that must be faced, photometers on the market are imported from abroad, so if damage occurs it will be difficult when it has to be communicated with the manufacturer.

Therefore we need an appropriate solution to maintain the essence of practicum as a scientific basis. One solution is to make your own photometer which is commonly called Do It Yourself (DIY) [12], [13] by reconstructing it from an existing photometer so that it is able to make your own simple photometer on a laboratory scale. This research was conducted to make a DIY Photometer and find out the tool's performance to complete the photometry practicum apparatus in the Astrophysics course.

II. Method

The materials used in this research are Arduino Nano, TSL237 Sensor, Infrared Filter, 1602 LCD Module, DS3231 RTC Module, MicroSD card Module, CR2032 battery, Micro SD Card, 60° LED Lens, 18650 battery Battery Module 18650 v3. The method used is an experimental method with data collection. The steps are as follows: first, a needs analysis is carried out, and then a photometer design is carried out. Followed by making a photometer and conducting limited trials, namely by measuring the Brightness of the Night Sky (NSB) with a limited scale together with the existing photometer, the SQM-LU type from Unihedron. The data obtained from the measurement results is the magnitude value per arcsecond². After that, perform an analysis of the data generated by SQM-LU and DIY Photometer and the effectiveness of the latest features in data collection.

III. Results and Discussion

Photometer Design Analysis

The photometer design is built based on a needs analysis so that various modules are embedded to meet the needs. The photometer that is already owned must be connected to a laptop for display and as a power source so that the photometer that is made must be a compact one with a screen feature that displays the value of mpas (Sky Brightness), Temperature, Date, and Time. In addition, it can record data and has internal power as a rechargeable battery.

This DIY Photometer design (Figure 2) uses an Arduino Nano, which has an ATmega328 microcontroller with 32 kilobytes of flash memory and 2 kilobytes for the bootloader [14]. The light sensor uses a TSL237 sensor with a high radiation responsiveness of $2.3\text{kHz} / (\mu\text{W}/\text{cm}^2)$ @ $\lambda = 524\text{nm}$, allowing this sensor to detect small changes in light [15]. The DS3231 module with a CR2032 battery as a power source is used for digital timing and the addition of a temperature measurement feature, then the use of an SDCard Module which functions to read and write data on a micro memory card. In order to directly know the NSB measurement value, the 1602 LCD module with I2C is used as a screen to display it, and as a resource, the 18650 V₃ battery module is used because it has a long resistance in providing power and can recharge.

Light collectors are used to collect light from the sky. These collectors are very inexpensive because they are made of plastic using injection moulding. These lenses are usually used to emit light in LED lamps, known as LED Lenses. The LED lens is used with a nominal type of 60° FoV (Field of View), which is commonly called the field of view. FoV will decrease because the position of the detector outside the collector based on the calculation of the Gaussian function becomes 17° FWHM [16]. The infrared filter cuts the detector's ultraviolet response below 400 nm and the IR response below more than 750 nm and is placed between the lens as a light collector and a sensor that will capture light. This ensures no unfiltered light reaches the sensor because the TSL237 sensor is sensitive to infrared (IR).

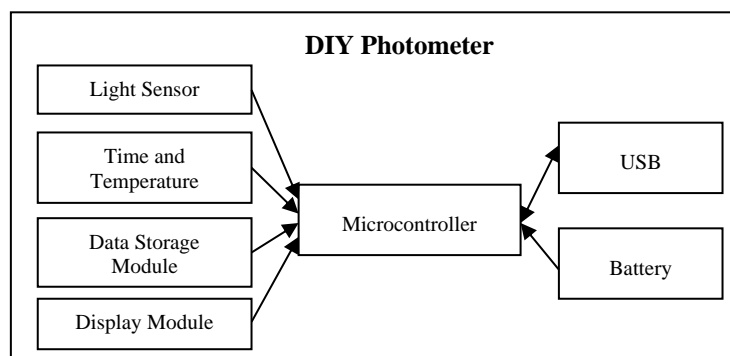


Figure 2. DIY Photometer Design

Photometer Making

The first stage is to assemble the Arduino Nano microcontroller with the modules and sensors on the test board (Breadboard) according to the data guide for each module and sensor. The LCD Module and DS3231 use the I2C (Inter-Integrated Circuit) line, a two-way serial communication standard using two channels specifically designed to send and receive data. The I2C system consists of SCL (Serial Clock) and SDA (Serial Data) channels that carry data information between I2C and its controller [17]. The MicroSD card module is connected using an SPI (Serial Peripheral Interface) line, one of the high-speed synchronous serial communication protocols owned by ATmega32. While the TSL237 sensor, which has three pins, is connected using a digital line on pin D8 for the data pin, the remaining two pins are on the Vc pin for voltage and the GND pin for Ground on the Arduino Nano microcontroller.

The second stage is creating programming code in the Arduino IDE by entering the library of the modules we use and then creating a command code to do the work we want from the module. The second step is to verify the programming code that has been made without errors. This step is very time-consuming because every code we use must be accepted by the microcontroller language so that the system can run. The third step is to upload the programming code to the Arduino Nano microcontroller so that it can do the job we want. Making the code to run SFS has gone through various trials and adjustments so that the programming language

that has been created can function properly, such as the selection of libraries for the modules used according to the ram owned by the Arduino Nano. The reading code for the TSL237 sensor is adapted from a code that amateur astronomer Daniel has developed from Sweden [18]. The flow of the SFS program code in the running of the instruments used by both modules and sensors can be seen in Figure 3.

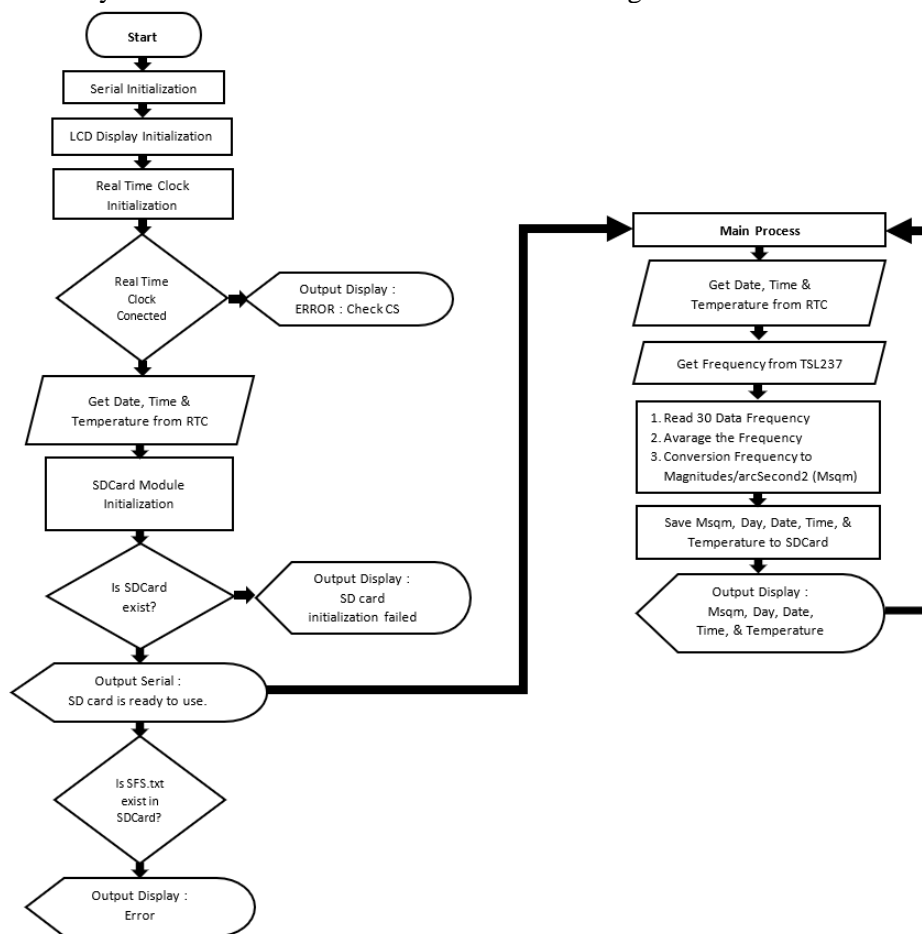


Figure 3. DIY Photometer Workflow

The process of packaging the instruments used goes through various trials to ensure the position of the module and sensor can function properly and the position of each is within a safe distance, and all are in one box that is used. In addition, the packaging of this DIY Photometer (Figure 4) must still have aesthetics and ease of use, including there is a special slot for removing and inserting the MicroSD card to facilitate data transfer after measuring the brightness of the night sky and there is also a special hole that can be connected to various types the existing tripod to facilitate the process of data collection.

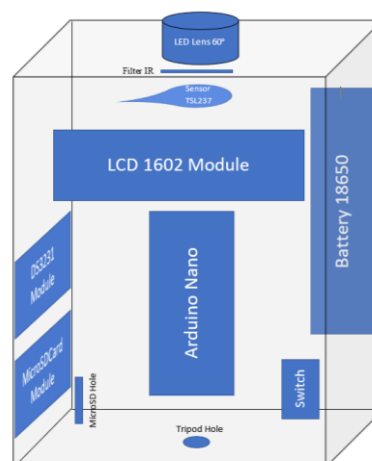


Figure 4. DIY Photometer packaging

Photometer Testing

At this stage, the DIY Photometer is used to measure NSB together with the SQM-LU photometer that already exists in the earth and space laboratory. Data were retrieved during the dead moon, July 28-29, 2022, located in Cimahi City with coordinates -6.8910587, 107.5372017. SQM-LU is set to be able to record NSB data in a span of 2 seconds, while SFS is set to record after the sensor measures the frequency of the captured light and converts it to NSB with a recording range of 1 to 4 seconds so that the amount of data generated by DIY Photometer and SQM is different in the time of data collection from 22:00 to 05:00 West Indonesia Time (WIT).

The results of the NSB recording are then plotted in a time graph against the NSB with units of $\text{mag}/\text{arcsec}^2$ (mpass), which can be seen in Figure 5 and Figure 6. From the two graphs, it appears that they have the same pattern, especially in the shape of the valleys and peaks, such as the first valley in Figure 6. time 22:17:00 to 22:18:00 WIB, the NSB SQM-LU value shows an average of 16.37 mpass and the NSB DIY Photometer value shows an average of 16.35 mpass.

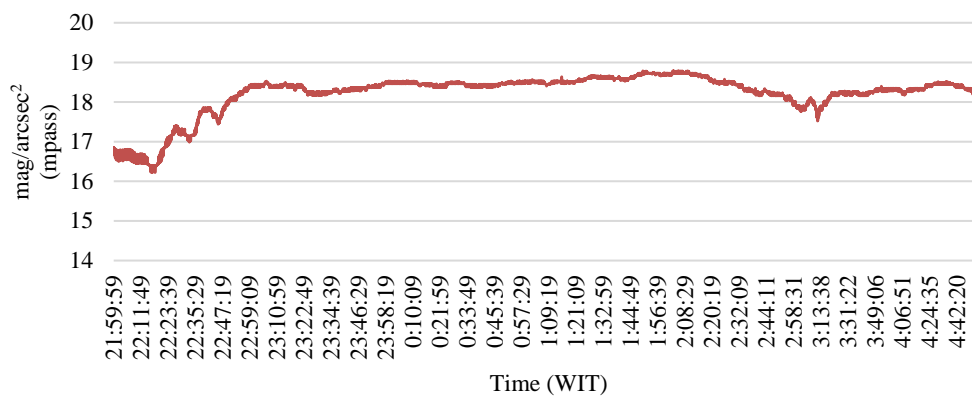


Figure 5. Night Sky Brightness on 28-29 July 2022 from SQM-LU

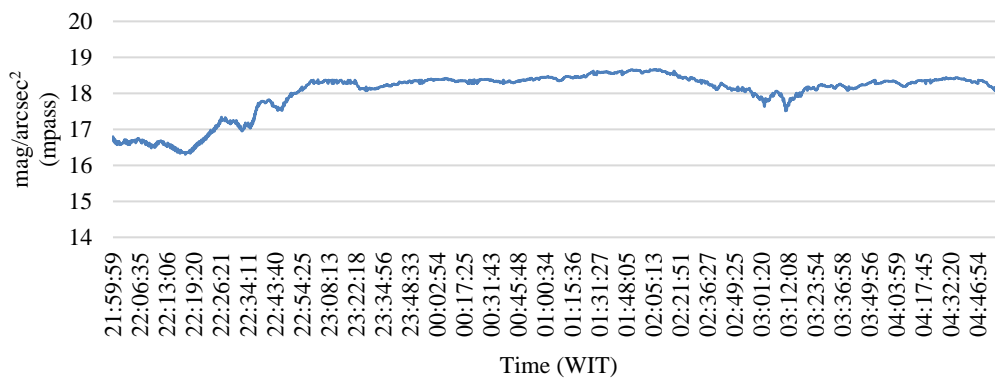


Figure 6. Night Sky Brightness on 28-29 July 2022 from DIY Photometer

From the graph, it can be seen that changes in the NSB value tend to be stable from 23:00 to 01:00 WIT. By calculating the average NSB value from the data recorded by SQM-LU and DIY Fotometer, NSB is 18.40 mpass and 18.35 mpass. Meanwhile, at 03:00 to 03.20 WIB from the SQM-LU and DIY Fotometer graphs, an anomaly appears with the appearance of valleys and peaks that may have passing clouds. The NSB value recorded in sharp valleys at 03:11 WIB in SQM-LU is 17.52 mpass and 17.51 mpass in DIY Photometer.

During 7 hours of measurement, the amount of data recorded by SQM-LU is 12724 data with a maximum NSB value of 18.79 mpass and a minimum NSB value of 8.25 mpass, while that recorded by DIY Fotometer is 10344 data with an NSB maximum value of 18.66 mpass and Minimum NSB value is 8.44 mpass. Based on the Bortle scale, the NSB value from both SQM-LU and DIY Fotometer is in the range of 18.38 – 18.94 mpass, which belongs to class 7 as shown in Figure 7, which has the title Suburban/urban transition area or suburban/urban Transition, the title is according to the map of the location of Cimahi which is on the outskirts of Bandung City.

Color Magnitude	Bortle Class	Sky Brightness	
		mag/arcsec ²	Artifi./Natural
7.6 - 8.0	1	>21.90	<0.01
7.1 - 7.5	2	21.90 - 21.50	0.01 - 0.11
6.6 - 7.0	3	21.50 - 21.30	0.11 - 0.33
6.3 - 6.5	4	21.30 - 20.80	0.33 - 1.00
6.1 - 6.3	4.5	20.80 - 20.10	1.00 - 3.00
5.6 - 6.0	5	21.1 - 19.10	3.00 - 9.00
5.0 - 5.5	6,7	19.1 - 18.00	9.00 - 27.0
<4.5	8,9	<18.00	>27.0

Figure 7. Bortle Scale [19]

According to the Bortle scale, Class 7 means suburban/urban Transition. The entire sky background has a faint greyish-white hue. The strong light source is visible in all directions. The Milky Way is completely invisible or barely visible. The M44 or M31 can be seen with the naked eye but is unclear [20].

To find out the NSB value when there is a moon in the night sky, measurements are made during the full phase, namely on 11 to August 13, 2022; SQM-LU is reset to record data every 4 seconds, so it is expected to have a number of data that is not too far from the data generated by DIY Photometer. However, on 11-12 August 2022, the laptop connected to SQM experienced problems, so the data recorded was only half the night, from 20.00 to 24.00 WIT. On 13-14 August 2022, measurements were performed again from 22.10 to 03.30 WIT. The results of the NSB measurement for two nights are then plotted in graphs in Figures 8, 9, 10, and 11.

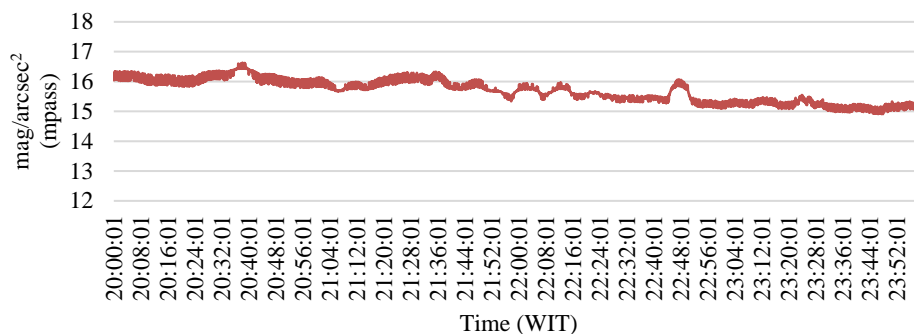


Figure 8. Night Sky Brightness at 11-12 August 2022 from SQM-LU

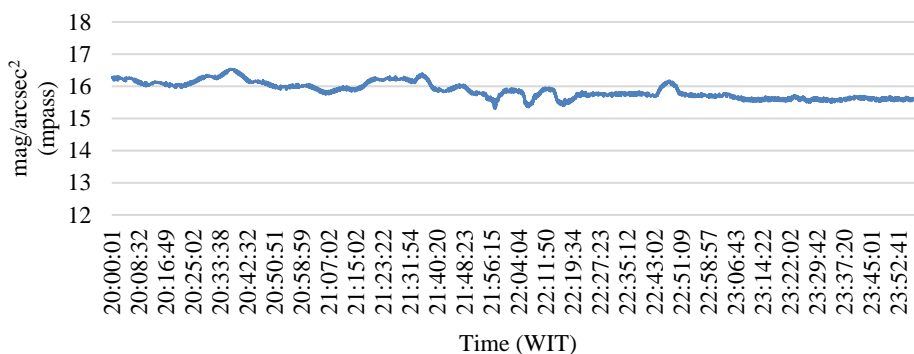


Figure 9. Night Sky Brightness on 11-12 August 2022 from DIY Photometer

Figures 8 and 9 illustrate how the NSB value tends to decrease as the sky begins to lighten by the moon. At 20:00 WIB, the moon is in the position of 36.80 and moving towards the position of 74.80 at 24:00 WIB,

with the Moon Illumination of 99.4 - 99.6% giving an effect on the NSB value on SQM with a maximum value of 16.63 mpass and a minimum of 14.91 mpass, in other words, a decrease of 17.3. Whereas in DIY Photometer, the maximum value of NSB is 16.53 mpass and a minimum of 15.30 mpass, which means a decrease of 1.23 mpass, this difference in the value of decline could be due to the position of the SQM and DIY Photometer storage, which are parallel to the east-west direction. Even so, if we observe, there is a similar profile of the chart pattern in Figures 8 and 9.

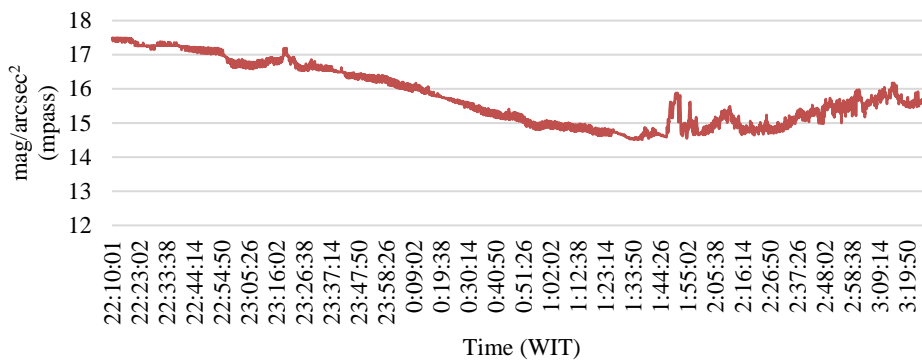


Figure 10. Night Sky Brightness on 13-14 August 2022 from SQM-LU

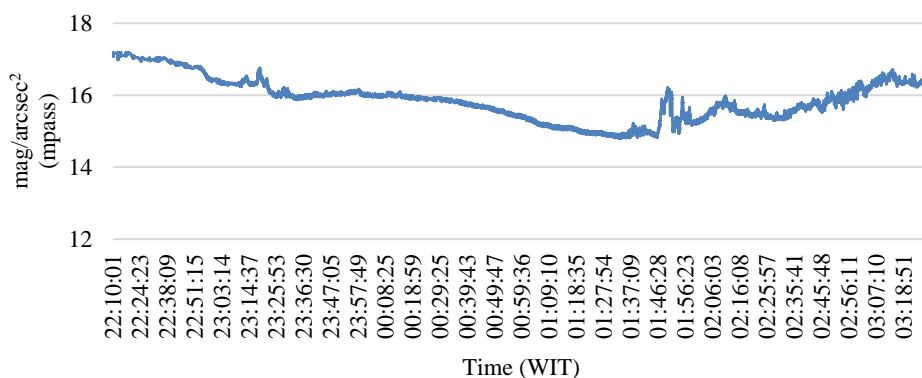


Figure 11. Night Sky Brightness on 13-14 August 2022 from DIY Photometer

From the graphs, both Figures 10 and 11 have the same pattern where it can be seen that the NSB value continued to fall from 22:10 to 01:34 WIB, often with the moon crawling up towards the zenith and slowly increasing the NSB value again until a dislocation was seen in the form of the spike in the NSB value then dropped back and rose again significantly at 01:46 to 01:58 WIB, this is the possibility of clouds passing over the moon, thereby proving that the DIY Photometer made has the same response as the SQM-LU.

IV. Conclusion

The DIY Photometer, which was made for photometry practicum in the Astrophysics course at the Earth and Space Laboratory of the Department of Physics Education, Universitas Pendidikan Indonesia, has been successfully carried out. This success can be seen from the test results of measuring the Brightness of the Night Sky at the time of the new moon and full moon, showing the same pattern based on plotting the mpass value against time, referring to the Bortle scale and DIY Photometer showing the class 7 title as shown from the SQM-LU results for measurements in Cimahi. Similarly, DIY Photometer can respond well like SQM-LU in measuring NSB changes when clouds pass by, so the DIY Photometer made on a laboratory scale can already be used in the photometry practicum process.

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