

Exploring Some Methods of Measuring Night Sky Brightness Levels

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Abstract

Sky brightness has an important impact on data collected from digital images. It produces environmental effects important in terms of ecology, human health and overall enjoyment of the night sky. Sky brightness can be monitored by a variety of different techniques. Recent systematic sky surveys enable long term monitoring of sky brightness. Simple astronomical instruments can be adapted to dedicated use for sky brightness monitoring. There are even a variety of specialized instruments designed for the sole purpose of sky brightness measurement. We discuss elements of each of these approaches. We present some results of how to compare the data collected, and examine how the data correlate using different systems. Support has been provided by Colorado State University, the Global Network of Astronomical Telescopes, Inc., the International Dark-Sky Association and Western Research Company, Inc.

1. Introduction

The International Dark-Sky Association (IDA) is a non-profit organization dedicated to preserving and protecting the night skies through the limitation of light pollution. As such, part of their work includes providing information about issues related to dark sky preservation. This information is made available to be used as an introduction to the subject for the general public, and as a guide to cities and government officials for policy formation.

While IDA's mission involves many varied topics, monitoring sky brightness is an important component. Looking at sky brightness as a function of time is especially vital. Being able to continually monitor any changes in sky brightness, whether due to time of year, lunar cycle, sky conditions, or long term city growth, provides valuable data on which to base technical recommendations.

Astronomers can productively contribute data to this goal. Setting up permanent telescope systems or reducing archives of already collected sky images provides a database for the ongoing study of sky brightness levels. Collaborating with independent astronomers creates a broader range of data, both over time and distances.

The study and analysis of various methods of sky brightness data collection is therefore undertaken to determine the best approach to meet IDA's needs. In this paper we summarize some of the efforts underway to monitor sky brightness using astronomical tools.

2. Methods

For purposes of this report we look at three techniques that we have used for monitoring sky brightness: 1) measurement of sky background in archived

astronomical surveys, 2) operation of dedicated astronomical telescopes for sky brightness measurement, and 3) a calibrated light meter specifically intended for sky brightness measures.

2.1 Archived Data

Some types of archived astronomical survey data are potentially useful for sky brightness measurements. These data are most useful in the case of surveys which are conducted over extended periods of time using homogeneous observing parameters and protocols, such as fixed integration times. One such survey to which we have access is the Moving Object and Transient Event Search System (MOTESS) that has been analyzed for stellar variability by the Global Network of Astronomical Telescopes (GNAT). MOTESS is described by Tucker (2007) and the GNAT analysis is presented by Kraus et al (2007).

2.2 Dedicated Telescopes

Another method of collection of sky brightness data is the set up of dedicated telescopes that specifically monitor sky brightness. We have set up two such identical systems in Fort Collins, Colorado and Tucson, Arizona. Each system is comprised of a 5 inch Celestron telescope equipped with a Santa Barbara Instruments Group (SBIG) ST-6 digital camera. The telescope is pointed at the zenith and is stationary, allowing the sky to sweep by. The digital camera is programmed in the CCDOPS control software to take a series of short integration (typically 20 seconds) images throughout the course of the night.

2.3 Light Meter

The final method considered is the use of the Unihedron Sky Quality Meter (SQM). The SQM is a small hand held device that measures the brightness of the night sky in magnitudes per square arc second (Cinzano 2005). The user points the sensor of the meter at the zenith and presses a button to initialize a measurement; in a few seconds a reading will appear on the screen. SQM measures were simultaneous with our dedicated telescope imaging; we were careful to point the SQM at the field of view of the telescope. Use of this meter is especially helpful as it provides an exact numerical value for sky brightness. Analyzing digital images in the first two methods typically only produces relative values, and as such results can only be looked at in a comparative sense.

3. Data Reduction

3.1 Archived Data

The MOTESS imagery consists of scan mode Flexible Image Transport System (FITS) astronomical images of the night sky, typically within 5 degrees of the celestial equator. These scan mode integrations are 193 seconds in duration and the telescopes are pointed at or near the prime meridian. MOTESS survey imaging commenced in Spring 2001 and has been continuous ever since, providing a long term and homogeneous data set suitable for night sky brightness monitoring.

Sky brightnesses were extracted from the images using the image histogram function of the astronomical image reduction software package MIRA (Axiom, Inc.; Tucson, AZ). The peak value of the darkest pixels in the image histogram was taken to be the average sky brightness value. These values were recorded in data numbers (DN), and as a result the data are useful for comparing relative sky brightness. Sky brightnesses were measured as a function of date and note was made of the lunar phase for the night of measurement.

These data are also useful for educational projects, and to this end we have used software such as SkyView (Western Research, Co., Tucson, AZ) to enable students to quickly and easily measure sky brightness and do star counts in archived image data (Craine et al. 2006).

3.2 Dedicated Telescopes

Nightly data collection began with activating and setting the camera temperature, in this case to -15 C, and setting the parameters for the evening's image collection. We kept the parameters fixed throughout the course of the five months of observation and had the same settings in both Fort Collins and Tucson. We set the integration time at 20 seconds, and arranged for the camera to continuously take alternate dark and sky images, with the darks automatically subtracted from each sky image. Images were taken throughout the night, depending on weather conditions. The Fort Collins images were more frequently degraded by frost accumulation on very cold nights; these images were rejected in the data reduction process. Including the download time an image was taken approximately every three minutes throughout the course of the night.

The Fort Collins system has run nearly continuously since November of 2007, while the Tucson system commenced data collection in early 2008.

We downloaded each evening’s set of images and opened them for analysis in the astronomical image processing software package MaxIm DL. Looking at the FITS header to determine the time that the image was taken we searched for the image closest to the time when the SQM readings were done. Opening that image we would then use an image histogram to determine the value of the sky background. We then recorded that value in an Excel spreadsheet, and repeated this process for each image of interest.

3.3 Light Meter

To collect data with the SQM we took a series of 5 readings, one right after the other, over the course of about 2 minutes. We would then average these 5 readings to determine our final SQM value. All the measurements were made in conjunction with the dedicated telescope observations to correlate the two in time. In Fort Collins one set of SQM measurements was taken each night, at times ranging from 9:00pm to 12:30am local time. In Tucson we are primarily considering SQM data taken from one night. On this night we took a set of SQM measurements once every 5 minutes for about two and a half hours. This gave us a relatively large range of brightnesses to analyze.

4. Results

4.1 Archived Data

The sky brightness measurements from the archived data can be examined on a nightly basis as a function of lunar phase and sky conditions. They can also provide information on long term trends in local night sky brightness.

In Figures 1 through 3 we see examples of a dark sky with a moonless night, a dark sky in which clouds form during the second half of the night, and a night during which a bright moon is moving toward the western horizon, setting shortly before sunrise.

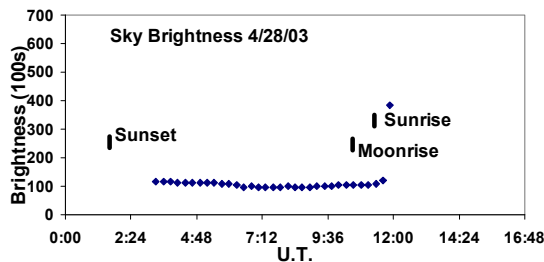


Figure 1. MOTESS images reduced during a dark night.

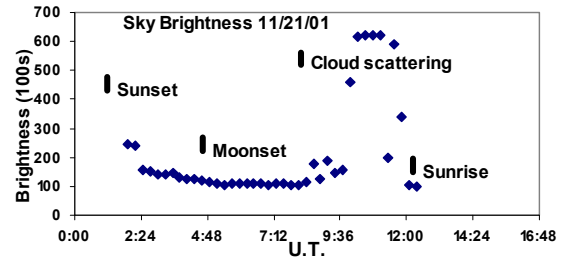


Figure 2. A dark night ending in cloud cover.

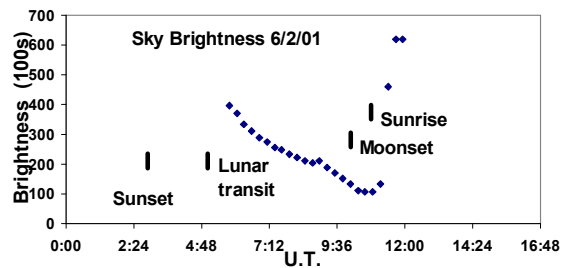


Figure 3. Bright moon setting.

Of particular interest to IDA, in conjunction with its public policy lighting ordinance programs is long term variation in sky brightness background. In Figure 4 we see an example of the use of MOTESS data to monitor sky brightness above the observatory (located in suburban southwest Tucson) over a period of several years. Detailed analysis of such time series data can provide insight into the effects of development and implementations of restrictive lighting policies.

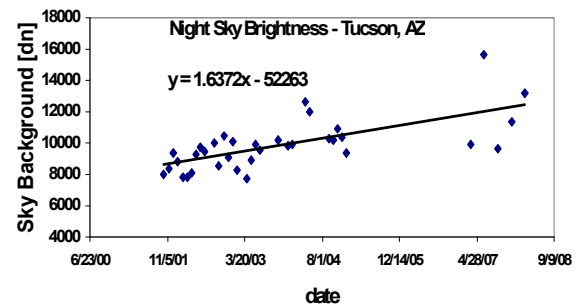


Figure 4. Long term sky brightness trends, Tucson, AZ.

4.2 Dedicated Telescopes

Data from the dedicated telescopes can be used to monitor nightly changes and trends in the sky brightness levels. They can also monitor nightly levels over a longer period of time.

Figure 5 shows the sky brightness levels as a function of time, over the course of one night observation. In this figure the sky brightness appears fairly constant until morning twilight. The same data are expanded in Figure 6 and are indicative of short term fluctuations in sky brightness; these fluctuations may be due to artificial light, as well as natural phenomena such as atmospheric particles.

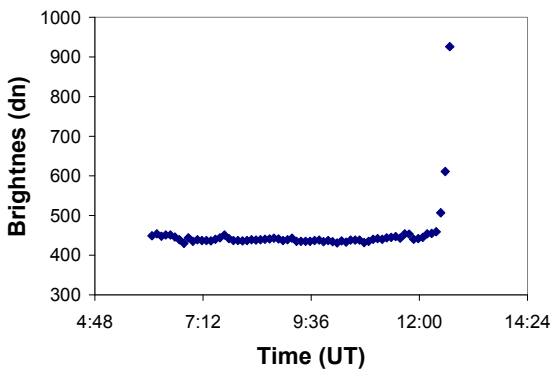


Figure 5. Sky brightness as a function of time (11/5/07).

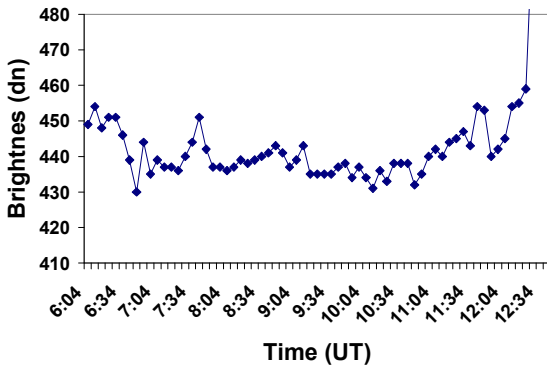


Figure 6. Short term scale sky brightness fluctuations.

4.3 Light Meter

Figure 7 shows the relationship between the two SQMs; SQM A used in Fort Collins, and SQM B used in Tucson. The two systems are not identical, as evidenced by the deviation of the slope of the least squares fit to the data from 1.00; but the correlation coefficient is high and the data track very closely.

The standard deviation about the mean of 5 nearly simultaneous SQM measurements was about 0.05 mag/arcsec²; thus the error bars in Figure 7 are

about the size of the icons representing each data point.

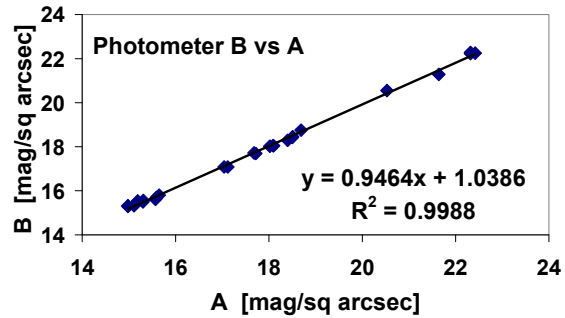


Figure 7. SQM reading comparison, unit B vs. unit A.

Figure 8 shows the relationship between the SQM readings and the brightness level determined from the telescope images. These data were taken over the course of several months.

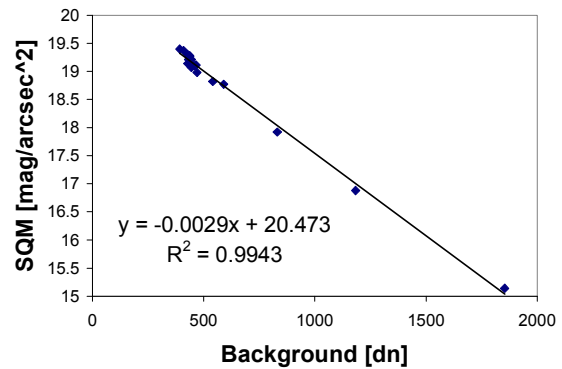


Figure 8. SQM and sky brightness comparison in Fort Collins.

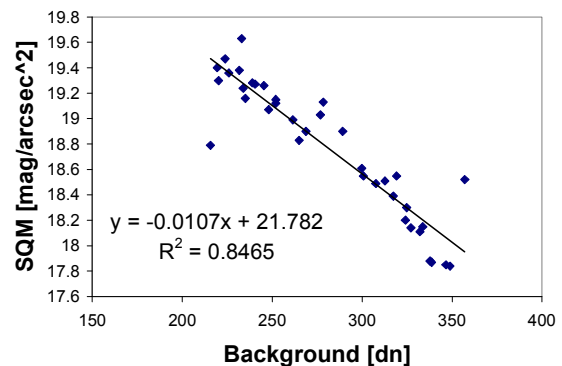


Figure 9. SQM and sky brightness comparison in Tucson.

Figure 9 shows the relationship between the SQM readings and the brightness levels over the

course of one night as observed in Tucson. In each case we have done a linear trend line fit to the data and the resulting equations are shown in the respective figures.

5. Conclusions

Some astronomical image archives can provide useful comparative sky brightness data. Low cost dedicated imaging systems can produce similar sky brightness data. They also have the advantage of being mobile and positionable at a variety of different locations.

SQMs provide a low cost, easy to use technique for monitoring sky brightness that can be calibrated to sky brightness measurements in digital imagery.

Using an appropriate calibration curve (similar to those derived in Figures 8 and 9) it would be possible to convert relative image brightness from other archives to absolute brightness values (in mag/arcsec²). This could be done by taking SQM readings at the same time and with the same telescope system, creating an applicable calibration curve that could then be retroactively applied to the archived data.

The methods we describe here are of value in developing technical databases to assist IDA in its policy making efforts. In addition, IDA has education regarding light pollution as a primary goal. We have found that using simple data reduction programs and astronomical imagery can be a powerful tool for providing such educational opportunities.

6. Acknowledgements

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7. References

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