Zenith sky brightness and celestial objects visibility during total solar eclipse on March 9, 2016 at Terentang Beach Bangka Island

A F C Wijaya[1], C P Asmoro[1], A A Rochman[1], T R Ramalis[1], J A Utama[1], N D Ardi[1], Amsor[1], M G Nugraha[1], D Saepuzaman[1], A Sutiadi[1] and D Nurfiani[2]

[1]Department of Physics Education, Faculty of Mathematics and Natural Sciences Education, Universitas Pendidikan Indonesia, Jl. Dr. Setiabudhi 229 Bandung 40154 Jawa Barat Indonesia
[2]Earth Observatory of Singapore, Nanyang Technological University, Singapore

Abstract. This paper endeavor to describe *sky brightness measurements* which was carried out by a team of total solar eclipse observers (TOGEMA) on 9th March 2016. The observations took place at Tarentang Beach, Bangka Island and it utilized the SQM-LU instrument (Sky Quality Meter–USB Connector) with 1 second time interval data. During total phase that lasted about 1 minute 52 seconds, the instrument recorded the brightness of the sky of 12.88 mag/["]^2 as the dimmest value. This value is approximately 500 times brighter than the dimmest night sky conditions at the same location, obtained on the previous observation. It was found that the brightest sky that could be measured by SQM–LU during Total Solar Eclipse (TSE) 2016 was 5.91 mag/["]^2. The activity with digital camera also captured the appearance of Venus and Mercury. The appearance of Venus (–3.71 mag) confirmed naked eye limited magnitude theory. This may explain the inability of observers to perceive Mercury (0.46 mag) using naked eye during the total phase of solar eclipse.

1. Introduction

Indonesia was the only country with a land traversed the path of totality in the event of total solar eclipse (TSE) on March 9, 2016. According to the US Space Agency, NASA, the TSE on March 9, 2016 was the 10th nature phenomenon which crosses Indonesian territory, where the 1st event was recorded back in 1901. Looking at the great potential that the phenomenon would contribute, Indonesian Government, through its Ministry of Tourism and Creative Industry, had designed an event dedicated to facilitate TSE observation all across Indonesian archipelago (shown in figure 1)

It is known that solar eclipse occurs when the Moon position is close to one point of intersection of the orbital plane of the Moon with the ecliptic. Meanwhile, TSE occurs when the angular size of the Moon observed from the Earth is equal to or greater than the angular size of the angle of the sun. The angular size of the Moon relative to the Sun will determine the duration of the total phase, and this event can be observed from a point on Earth's surface. Theoretically, the calculation for the longest duration of the total phase and the widest Moon umbra projected on the surface of the Earth respectively can reach 7.5 minutes and 270 km. During TSE on 9th Marth 2016the total phase lasted the longest in the western Pacific Ocean region for ~ 4 minutes with a Moon umbra width of ~155 km.

Such phenomenon also provides great research possibilities. First, TSE National Committee under the command of the National Institute of Aeronautics and Space (LAPAN) was established in 2015 to

coordinate research activities of various research groups both inside and outside the country as well as becoming the center scientific information to the public and the media. At UPI (Universitas Pendidikan Indonesia), The Laboratory of Earth and Space the Department of Physics Educationalso formed a Solar Eclipse Observation Team (TOGEMA), aimed to conduct observations and research regarding this event. Therefore, the paper reported one of the observations and measurements made by TOGEMA related to the brightness of the sky during the phases of the solar eclipse.

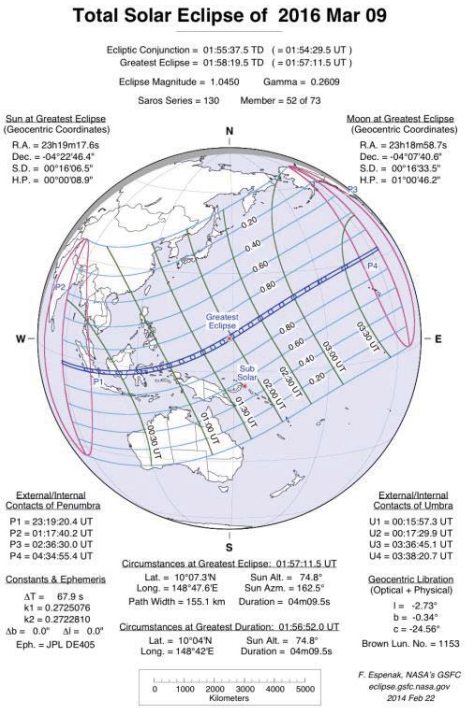

Figure 1. Total solar eclipse visibility chart and eclipse circumstances on March 9th, 2016.

2. Observations and measurements

TOGEMAs' TSE observations were held on the Terentang beach (2° 26 '39 "south latitude, 106° 19' 36" east longitude, 2.5 meters above sea level), Bangka Island, Bangka-Belitung. The location was selected since Bangka has the closest location to Java traversed path of eclipse totality. Moreover, the local government had also prepared adequate public facilities for tourists and researchers who came to the site.

It was noted that several contacts were made during the eclipse. The 1st Contact (C1), which was when the Moon and Sun disc-outer contacted, to mark the start of the eclipse, occurred at 06:20:58 local time. At the time of the height of the Sun on the horizon ~ 4°. This phase was not successfully investigated and enshrined as there were clouds covering the horizon in the direction of sight to the sun. After the first contact, the Sun disk was slowly covered by the Moon disk, where it eventually closed. This was called the 2nd contact (C2), which marks the beginning of the total phase, when the disk of the Moon and Sun in contact for the first time. This was recorded at 07:22:11 local time. At that time, the Sun elevated ~ 19° on the horizon, and it was not obscured by clouds. . The duration of the total phase at the site of the observation lasted about 1 minute 52 seconds and ended simultaneously with the 3rd contact (C3), that was when the Moon and Sun contacted for the second time at 07:24:03 local time. The end of the eclipse was marked by the 4th contact that was when the Moon and Sun in contact-beyond the second time, noted at 08:34:01 local time. TOGEMA team had managed to observe and capture the phases of TSE with pictures and videos.

During the phases of the eclipse, the team had successfully performed measurement of the change in sky brightness in the direction of the zenith, by means of instrument SQM-LU (Sky Quality Meter-USB Connector), connected to a laptop with 1 second time interval data. The SQM-LU stated the sky brightness in units of magnitude per arc second squared (mag / ["]^2), which is the unit commonly used for the extended light sources. The electronic guide book, which can be accessed on the manufacturer page (http://www.unihedron.com), mentioned that this tool has been calibrated with an accuracy of 10% (± 0.1 mag / ["]^2) and darkest sky conditions that can be measured is 21.80 mag / ["]^2.

3. Results and discussion

The zenith sky brightness variations during the phases of the eclipse are shown in figure 2. Measuring the brightness of the sky in the direction of the zenith had actually been carried out since the night before. This measurement was to obtain information on the condition of the dimmest night sky on the observation site, to be compared with the current situation of the total TSE phases. The dimmest night on Terentang beach occurred just after midnight, which was at 03:07:34 local time, with the results of measurements of 20.66 mag / ["]^2. Towards the rising Sun on March 9, 2016 at 06:01:10 local time, the condition of the horizon at sunrise azimuth and zenith direction gradually becomes clearer. SQM-LU could still perform before experiencing saturation due to the brightening of the environmental conditions, were 5.91 mag / ["]^2. The similar sky brightness recouped ~ 9 minutes into the 2nd contact and ~ 7 minutes after the 3rd contact. From the measurement results, it was concluded that the condition of the sky toward the zenith which was able to be measured by SQM-LU at 2016 GMT during the observation was 5.91 mag / ["]^2. This equated to 700 cd/m^2, which was similar to typical Saturn surface brightness with a magnitude of -0.4 and an angular diameter of 20.5" [2].

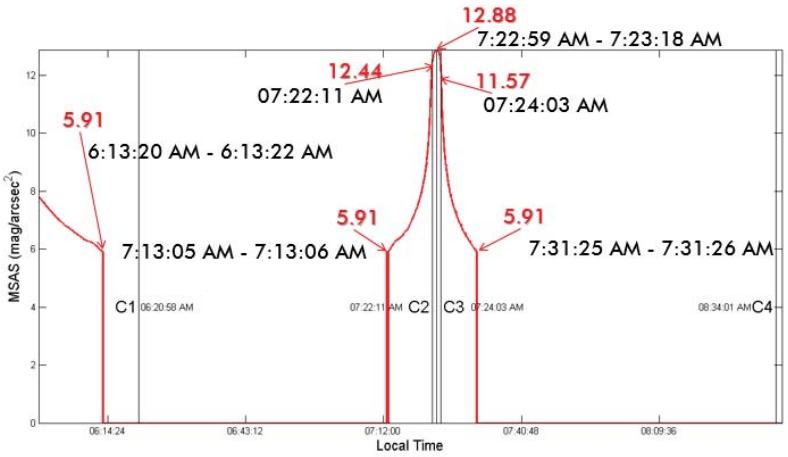

Figure 2. Data plotting of SQM–LU measurement during TSE March 9, 2016.

Meanwhile, the dimmest condition of the sky in the direction of the zenith recorded by SQM-LU during the total phase lasts was 12.88 mag / ["]^2, which lasted only for 19 seconds (07:22:59 - 07:23:18 local time). In magnitude, the greater the number means the dimmer object or condition of the sky. The results of these measurements showed that the dimmest conditions during the phase of total eclipse was still lighter (~ 500x) than the condition of the darkest of the night sky that has been measured on the previous night. It is because of the contribution of the distribution of light (light scattering) originating from outside the Moon's umbra [3]. For other locations on the Earth where partial solar eclipse (PSE) occurred, the conditions at the peak of the eclipse would relatively be lighter since the Sun light was still at sight.

During the TSE observations, one of the team members was able to observe the presence of Venus with unaided eye. The position of the Sun in the sky is in the direction of Aquarius, but none of the brightest stars of the zodiac members were visible. The Landscape digital image of the Eclipse also

identified the appearance of Venus and Mercury. Reports of success Venus observation (-3.71 mag) corresponded to the magnitude of the threshold value of the unaided eye (-0.8 mag) based on the brightness of the sky (12.88 mag / ["]^2) during the total phase. The magnitude were obtained with a correlation derived by K. Fisher, one of the SQM, which is available on the manufacturer's webpage (http://www.unihedron.com/projects/darksky/NELM2BCalc.html):

$$V_{naked-eye} = 7.93 - 5 \times \log\left[10^{\left(4.316 - \frac{m_{sky}}{5}\right)} + 1\right] \quad (1)$$

Figure 3. *(Left panel)* Sky simulation at the moment of total phase at Terentang beach using Stellarium software. *(Right panel)* Identification of planet Venus and Mercury (yellow circle) in digital image obtained using pocket digital camera NIKON Coolpix P520 f/3.1, 1/8 second, ISO 450 during total phase.

With a smaller magnitude than the unaided eye magnitude threshold, Venus was easy to be observed during the total phase. On the other hand, it was difficult to observe Mercury at the time, since it had a magnitude which was fainter than magnitude threshold, namely 0.46. To ensure that the observed was Venus, the team members compared the digital image obtained on the resulting simulation software Stellarium (www.stelarium.org) as shown in figure 3.

4. Conclusion

The results of the measurements of sky brightness at the zenith direction during TSE 2016 phases showed that brightness values changed rapidly, particularly towards the peak of the eclipse (the 2nd contact to the peak of the eclipse), and sometime after the peak of the eclipse (the 3rd contact). Not all sky brightness during phases of the eclipse were successfully measured due to the limited value sensor. The maximum brightness is 5.91 mag / ["]^2. Conditions of the darkest skies in the direction of the zenith during the total phase was 12.88 mag / ["]^2, which was equivalent to the magnitude of the threshold by unaided eyes - 0.8 mag. With the threshold value of this magnitude, the appearance of Venus during the total phase lasts had been successfully verified. Meanwhile, the appearance of Mercury which could only be observed through the digital imaging, was described, since this object had a magnitude fainter than unaided eye magnitude threshold.

Acknowledgments

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