Stellar background observation during Total Solar Eclipse March 9th 2016

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Abstract. We report observation and an early analysis of stellar background from total solar eclipse in Ternate, Indonesia. The eclipse phenomena which occurred on March, 9th 2016 was observed with certain portable instruments in order to obtain the stars behind the Sun in particular field of view and resolution. From our observation site in Ternate city, solar eclipse occurred in the late morning when the weather was unfortunately cloudy. However, during the darkness of totality, we obtained several point source objects between the gaps of the moving clouds and we suspected them as very faint stars due to their appearance in several frames. Those so called stars have been identified and measured with respect to their positions toward the center of the Sun. The main purpose of this research is to revisit strong lensing calculation of the Sun during total solar eclipse by measuring the deflection angle of the background stars as it had been calculated by Einstein and proved by Eddington at a total solar eclipse in 1919. To accomplish this aim, we need to conduct another observation to measure position of the same stars in the next period when those stars appear in the night sky.

1. Introduction

Our team proposed a research to revisit strong lensing calculation by measuring the displacement of the background stars during Total Solar Eclipse (TSE) March, 9th 2016. The deflection angle was calculated by Einstein with General Relativity Theory ($\alpha = 4GM/c^2 R$), which leads to an apparent displacement at the solar limb amounting to 1"75 [1]. It was successfully proved by Eddington and Dyson in TSE May, 29th 1919 and also been repeated several times by astronomers around decades [2] [3]. However, among 70 TSEs occurred between 1916 until 2015, not all observation were successful due to some challenges such as weather, location, instruments, very short TSE moment, politics, and so on. Therefore, we consider TSE March, 9th 2016, as a notable rare phenomena, is important to observe particularly to revisit lensing calculation. Nevertheless, to obtain the displacement, we still have to observe the stars in the night when there is no Sun’s gravitational effect as comparison field taken at night five months later [2]. Accordingly, in this paper, we only report about TSE observation aiming for early analysis of stellar background from TSE March 9th 2016 by identifying and measuring several detected point sources.

This noteworthy eclipse event was observed at Eastern part of Indonesia, Ternate, which lies at longitude 0°47N, latitude 127°22E, and altitude of about 5 m. In Ternate, the occurrences of TSE
began at 00:51:43.3 UT with the maximum at 00:53:0 UT, and lasting until 00:54:19.1 UT (2'46"). Considering the distant expedition, we were indeed planning to use only portable telescope and simple detector. However, in order to obtain the desired resolution and field of view, several configurations of telescope and detector were calculated and also tested. In special case of portable telescope, small telescope can perform better resolution than telescope with wider diameter and longer focal-length in visual wavelength [4]. It means low cost simple telescope can also give good performance with the suitable detector. Finally, we used Vixen ED Apochromatic Refractor 103mm f/7.7 mounted in German Equatorial SXD2 and 22.2 x 14.9 sized CMOS sensor built in DSLR Canon EOS Rebel T6s, performing image size 6000x4000 and pixel size 3.7μm. This detector features a new high resolution of 24.2 Mega Pixels coupled with 7560 pixels RGB, and has maximum ISO at 25.600. This configuration gives desired performance of resolution 0.96", area 1.71sq', and limiting magnitude around 13.

2. Method

2.1 Simulation of displacement
Displacement of the background stars due to gravitational lens during TSE was simulated in figure 1. The first zone which is illustrated in yellow bar indicates solar radius (R☉), therefore no star can be seen at this region. Second zone, 1< R☉<2, is region with the biggest deflection angle of the sun, however the stars are hardly seen due to coronal intensity. Meanwhile, region R☉>2 as the radius further away from corona, the deflection angle is become smaller.

\[ \text{Figure 1. Hyperbolic plot derived from Einstein equation which shows deflection angle estimation vs R☉} \]

\[ \text{Figure 2. Simulation of displacement of the background stars due to Sun’s gravitational lens during TSE.} \]

Simulation of figure 2 shows the displacement between random blue dot stars and red dot stars. Red dots correlate with the random stars after going through gravitational lens effect of the sun. Both simulation figures are important as consideration in choosing appropriate instrument configuration and for the preparation.

2.1 Observation method and processing
We began to observe and take image of the sun since 07.26 LT, about an hour before first contact. Ternate was chosen due to its good weather prediction for the eclipse day. However, this long term meteorological prediction in particular area was incorrect as the sky around the sun was covered by clouds since the first to the fourth contact of 9 March 2016 solar eclipse. Finally 29 frames of TSE were acquired with different ISO and exposure adjusted to the clouds, even though all of them were not as good as we expected and even some of them were very noisy.
Although no ideal image were taken, corona composite from raw data was perform quite well for cloudy data following the steps from Espenak [5] and Druckmuller, et all [6]. However, no star appears at the final composite still. Therefore we considered another steps for quick look and preliminary analyst. First, with the naked eye we searched appearance of dots in each frames. Among 29 frames, there was no visible star obviously until we zoomed them in to see details and finally found some point sources that we suspect as stars. Same sources appear in several frames, while the others only appear once. Then using MaxIm DL, images with same position of point sources were stacked for higher SNR [4]. The real measured profiles are close to two dimensional Gaussian profile [7]. Accordingly, we fitted Gaussian profile to collect information (FWHM & SNR). After that we measured the position towards the center of the Sun with AstroImageJ. We determine position of the sun and point sources using true direction seen from crescent solar partial eclipse.

3. Result and discussion

4.1 Source identification

We obtained 4 point sources from 3 group frames as it seen on figure 3 and listed on Table 1. This table gives information of name list of the objects suspected as stars which is shown that SNR source 2_1 is very low to be categorized as star.

![Figure 3. Identification of point sources](image)

| name  | frame   | SNR  | FWHM | Intensity |
|-------|---------|------|------|-----------|
| source 1_1 | 71,72,74 | 6.3  | 8    | 1598      |
| source 1_2 | 71,72,74 | 1.52 | 17.052 | 484      |
| source 2_1 | 84,85   | 0.142| 3    | 87.98     |
| source 3_1 | 90,91,92 | 23   | 1.5  | 1339      |

Figure 4 shows each images with their Gaussian plot and area plot. The stars image with the Gaussian profile is usually spread over several pixels [7]. Therefore all of them are suspected as faint stars in TSE according to intensity and Gaussian plot.

![Source 1_1](image)

![Source 1_2](image)
4.2 Source measurement
The apparent position toward the center of the sun can be seen in figure 3, while the measurement is shown in table 2. As gravitational lensing from the Sun has more effect to the sources in 1< R⊙<2, source 1_1 and source 1_2 will result better in displacement measurement later on.

Table 2. Measurement of Each Sources

| Name    | Length (pxl) | Length (km) | ratio to R⊙ | X    | Y    |
|---------|--------------|-------------|-------------|------|------|
| r sun   | 1463.452     | 695.7       | 1           | 2812 | 1779 |
| source1_1 | 2212.81     | 1052.341    | 1.513       | 1725 | 744  |
| source1_2 | 2181.955    | 1036.629    | 1.490       | 2490 | 287  |
| source2_1 | 3261.912    | 1550.68     | 2.229       | 720  | 994  |
| source3_1 | 4191.998    | 1994.734    | 2.867       | 5646 | 1799 |

In figure 5, true direction is measured using partial eclipse image taken right before TSE. From our field of view, the sun’s image tilts around 49.13° toward the real north position of the sun. This true direction can be used for measuring the point sources coordinate and further identification.

4. Conclusion
It is rather difficult to recognize very faint sources around the sun during TSE with thick clouds. However, four points sources were identified and measured toward the center of the sun even though one of them (source 2) might failed to be categorized as a star due to its low SNR. As it seen on Gaussian fitting, all of them still have a possibility to be the stars. Simple measurement shows that two sources (source 1) would be a good example of lensing effect. After all, it needs better measurement and coordinate transformation in right ascension and declination to obtain the exact position and the real name of the sources to be compared with the next observation.

Acknowledgements
We are thankful to some lecturers and graduate students in ITB, and astronomers in LAPAN for the discussion. And we also thank Space Science Center - LAPAN for supporting our expedition in Ternate and joining ISSEL. And we also thank the committee for giving us the opportunity to publish our research.
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