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Identification of moon craters and solar corona during total solar eclipse on 9th March 2016

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Abstract. Total Solar Eclipse (TSE) is a rare natural event in which the positions of Sun, Moon, and Earth are perfectly aligned. In the past by using this phenomenon, many researches have been done to understand characteristic of the corona. In this paper we carried out the study of TSE which crossed over Indonesia from West to East on 9th March 2016. We observed TSE which occured in Palembang (2.9883° S 104.7513° E), Indonesia. The aim of this research is to understand the effect of moon craters on the appearance of solar corona and identification of solar active regions during TSE. This research was done using Canon SX170 IS camera with ND 5 sun-filter. Although the sky was cloudy during the totality of the phase, coronal video was still taken. Camera also took solar images of partial eclipse phase. Coronal images for every frame were then extracted from the video. Image processing of coronal images was done using RegiStax and PhotoScape freewares. To study solar corona, images from Virtual Moon Atlas, Hinode XRT, and SOHO-LASCO were compared with the result of oriented coronal image. Wider and many more moon craters were found having positive correlation with the brighter effect on solar corona as shown at westward coronal streamer. Those craters are represented by Bel'kovich crater, the biggest one. We also found that only the eastward coronal streamer was correlated with active region, sunspot number 12519, from behind solar limb.

1. Introduction

Total Solar Eclipse (TSE) occurs when the moon's shadow covers the entirety of the sun's disc. As the center of moon's shadow crosses the center of the sun's disc, so TSE becomes rare phenomenon. Observing TSE on the ground can pave the way to study coronal activitiy in cheap and valuable method [1]. This method can use digital camera for many exposures to cover many solar radii. Druckmüller did this method for discovering of a new class of coronal structure [2].

TSE which crossed over Indonesia on 9th March 2016 has saros series 130 . This series shows that the Moon was moving northward, and that the TSE occured at the Moon's descending node. This TSE started from West to East Indonesia in the morning, with different initial time at every place. By using this natural event, we studied coronal appearance during totality. The aim of this research is to investigate the effect of moon craters on the appearance of solar corona and the identification of solar active region during TSE. We observed the TSE that occured in Palembang (2.9883° S 104.7513° E), Indonesia, which started from 23:20:29.3 UT to 01:31:25.3 UT on 8th to 9th March 2016.

2. Methodology

We took both video and images of the eclipse phase which started from 6:20:29 to 8:31:26 Western Indonesian Time. Data were taken using Canon SX170 IS camera integrated with sun filter ND 5. Camera was attached to a tripod which could move in altitude and azimuth and took video of totality phase and image of partial phase. Due to an unfortunate circumstance, the sky was significantly covered with clouds, so that the Sun was barely visible, with only several phases of the TSE able to be observed. Allignment of solar coronal image usually can be done by a modified phase correlation method, based on Fourier Transform [3]. This method could be conducted if coronal images were clear from cloud. Since only several regions of corona appear during total eclipse phase, so another simple method is used on this research.

Video of the total phase were converted into images with 25 frames per second. Registax 6.0 was used for stacking images and improving image results. The images were then rotated using Photoscape v3.6.3, which was based on the orientation of the Sun at real time. Orientation of the Sun at totality phase was derived from orientation of the Sun at partial eclipse phase. Orientation of the partial eclipse was aligned using data from "https://www.solarmonitor.org/". After orientation of the total eclipse had been applied, the solar corona was analyzed using Virtual Moon Atlas and Solar Monitor web in order to identify moon craters and solar active region respectively. Westward of the solar disc was on the right side of the frame, whereas westward of the moon disc was on the left side.

3. Result and discussion

The clear images of partial eclipse were captured on 24 jpeg images. These data were then used to derive the rotation angle at total eclipse phase. Every rotated frame was built using Photoscape for the partial eclipse phase, both before and after the total eclipse phase. Orientation was based on the solar monitor web for Hinode XRT (X-Ray Telescope) data. Every rotation angle of all the partial eclipse phase images is shown on figure 1. The first clear image was created at 7:04:55 am and had a rotation angle of 74.5°. As time went on, the rotation angle was decreasing with 2 different regression types. The first fitting which occured before 7:33:25 am has a regression type of 2nd order polynomial. Rotation angle of its fitting dropped significantly with time. This was caused by a refraction of the thick atmosphere near the horizon. The secondary fitting which occured after 7:33:25 am has a linear regression, accounting for the slower decrease of the rotation angle than that of the first regression. Two kind of regressions are choosed by the biggest coefficient determination, R^2.

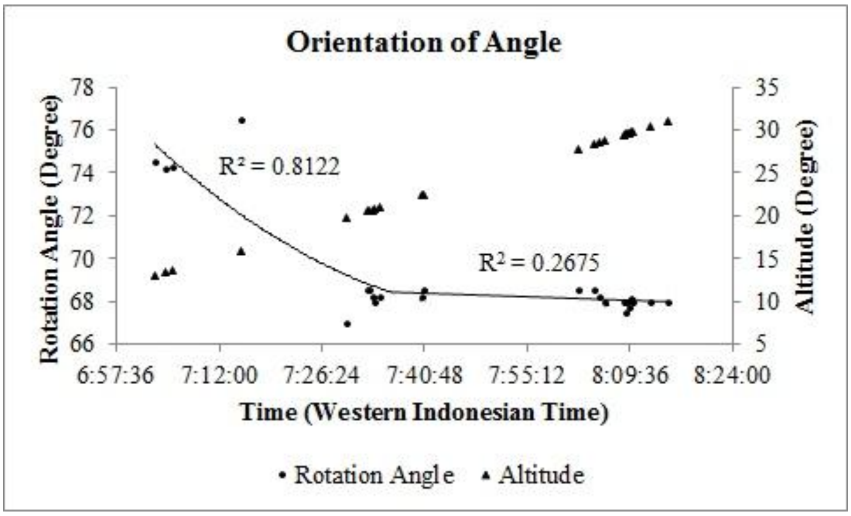

Figure 1. Angular orientation of each phase of the partial eclipse.

From the total eclipse phase MOV video, 275 jpeg images were generated. These images were stacked to become a single image, and then improved using Registax image processing. The total

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eclipse was captured at 7:21:23 am Western Indonesian Time. Based on this time, the total eclipse phase image has an average rotation angle of 71.05°. This angle was derived from the 2nd order polynomial regression as shown on figure 1.

3.1. Identification of moon craters

Orientation of the solar disc during total eclipse phase was stacked with lunar images at respective times of totality phase as shown on figure 2. Solar corona had been detected on the rightward and leftward of figure 2. Rightward corona is on latitude 45° to 82° and longitude (87±5)°. Then, leftward corona is on latitude 0° to 30° and longitude –(92±5)°. Craters in this region are chosen for craters which are on arbiter line which separates dark and bright sides of the Moon. By using these borders, the moon craters in this region are shown in table 1.

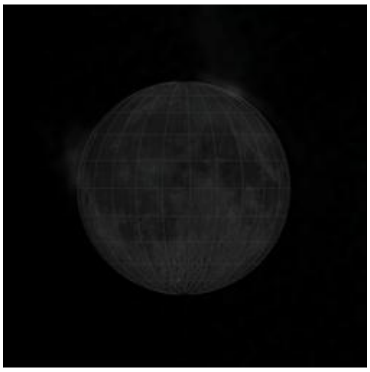

Figure 2. Stacked Lunar and Coronal Images at total eclipse phase.

Table 1. Moon Craters at Coronal Region

IAU Feature Name	Lat. (°)	Lon. (°)	IAU Diameter (km)
Petermann A	74.85	87.63	18.34
Hayn G	66.86	86.31	20.11
Bel'kovich A	58.65	87.41	57.26
Hayn F	68.01	85.75	62.54
Nansen	81.17	95.38	116.90
Bel'kovich	61.53	90.15	215.08
Einstein S	15.10	-91.67	19.63
Einstein R	13.83	-91.88	19.84
Sundman	10.76	-91.69	41.04
Moseley	20.95	-90.20	88.89

Data show only several region at solar limb which have coronal appearance. This appearance could be affected not only by clouds, but also by moon craters. As shown on figure 2, rightward/ eastward Moon has many more wide craters than leftward/ westward Moon has, so eastward region is brighter than westward region. Coronal region on eastward Moon is represented by Bel'kovich crater. On another side, coronal region is represented by Moseley crater.

3.2. Identification of solar active region

Other than moon craters, coronal appearance is also influenced by solar active regions. Therefore, solar corona can be identified by identifying solar active region. Images of solar active region and corona are shown on figure 3. Corona on eastward and westward solar disc were expected to have the same feature as Lasco C2 showed. However, stacked image between the data and image from Lasco

C2 shows differences in their coronal features. The eastward corona in Lasco C2 image is brighter than its corresponding westward corona and data show the opposite. Regions with brighter corona on Lasco C2 image show the effect of CME (Coronal Mass Ejection) which detected on eastward limb with a radial velocity of 688 375 km/s and angular width 6° ("https://www.heloviewer.org"). Based on Hinode XRT data, coronal appearance on eastward limb was affected by active region, sunspot number 12519, which is behind solar limb. This active region could be seen a couple of days after 9th March 2016, since it had direction of rotation from east to west. Active regions image from Hinode XRT shows loops above sunspots which represent strong magnetic field. Regions with strong magnetic field have high temperature, as magnetic energy is converted to thermal energy [4].

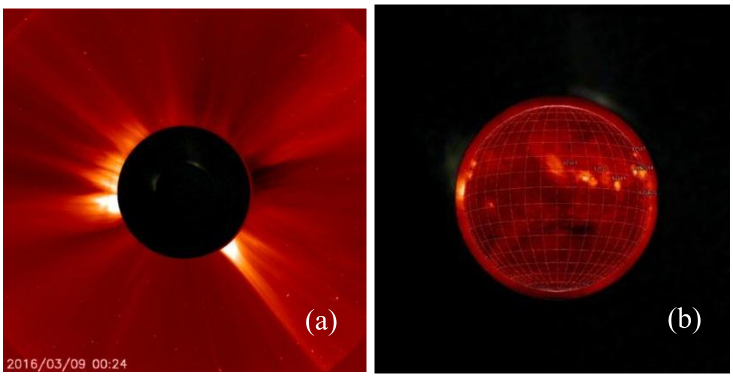

Figure 3. Corona from TSE stacked with solar active region image. (a) Stacked with SOHO Lasco C2 (b) Stacked with Hinode XRT.

4. Conclusion

By using a simple method which defining orientation based on partial eclipse phase, orientation of the Sun during TSE had been obtained. This method also showed an atmosphere refraction effect in the morning, before 8 am at local time. This simple method could be used for bad data, such as uncomplete corona because of clouds.

Coronal features during TSE were found having positive correlation with size and abundance of moon craters. On bright corona, coronal westward of solar disc, was correlated with wide and many of moon craters. On another side which had dim corona, coronal eastward of solar disc, was correlated with narrow and lack of moon craters. Both sides are represented by Bel'kovich and Moseley craters respectively. Coronal appearance was also influenced by solar active regions. Eastward coronal features had positive correlation with coronal appearance on Lasco C2, which is influenced by CME and active regions behind the solar limb, sunspot number 12519.

5. Acknowledgement

The SOHO/LASCO data used in this paper were produced by a consortium between the Naval Research Laboratory (USA), Max-Planck-Institut fuer Aeronomie (Germany), Laboratoire d'Astronomie (France) and the University of Birmingham (UK). SOHO is a project of international cooperation between ESA and NASA. *Hinode* is a Japanese mission developed and launched by ISAS/JAXA, with NAOJ as a domestic partner and NASA and STFC (UK) as international partners. It is operated by these agencies in co-operation with ESA and NSC (Norway).

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