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Infrared radiometric measurements of lunar disk temperatures during lunar eclipse on 15th June 2011

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Abstract

Radiometric measurements of the total lunar eclipse on 15th June 2011 were carried out at the KACST observatory (lat. 21.25 N; long. 49.30 E), Jeddah, Saudi Arabia, using a locally designed, constructed and calibrated infrared detector. The basic detector is a Heimann TPS 534 thermopile with a 3° field of view and operating at wavelengths between 8 μm and 14 μm. The total phase of this eclipse lasted about 100 min, making it one of the darkest eclipses this century. The lunar temperature curve of this eclipse was obtained and showed comparable behavior with previously established infrared observations. We found that the lunar surface temperature decreased by about 147 K and 220 K during the partial and total eclipse phases, respectively, in comparison with the lunar temperature before the eclipse.

Keywords: 2011 total eclipse; Infrared measurements; Temperatures of the moon; Saudi Arabia; Lunar disk

1. Introduction

Due to its closeness to the Earth, optical observations enable astronomers to identify, with greater detail, more features of the moon's surface than any other object in the sky. With the advance in radiation detector technologies in the middle of the last century, radio and infrared telescopes have helped researchers to explore the lunar surface in finer detail than was previously possible. For different scientific purposes, including lunar exploration missions (Spudis, 2008; Paige et al., 2009; Vondrak et al., 2010), detailed geographic, topographic and spectral information about the lunar surface is of great importance (McEwen and Robinson, 1997; Palle et al., 2009; Shaw et al., 2015). The temperature of the lunar surface is an important factor in determining the physical properties of the lunar surface's materials (Vollmer and Mollmann, 2012). These include the composition, thickness, density and conductivity of the lunar regolith (Ryadov et al., 1964; Linsky, 1966; Johnson et al., 1993; Mukai et al., 1997; Lawson et al., 2003; Vasavada et al., 2012; Williams et al., 2012). Due to its slow rotation, the lack of atmosphere and the low conductivity of the regolith layer, the lunar surface temperature varies greatly from day to night (Long, 1998; Jianqing et al., 2010).

Lunar surface temperatures have been studied during different moon phases and during eclipses using infrared and microwave wavelengths (Pettit and Nicholson, 1930; Piddington and Minnett, 1949; Sinton, 1963; Saari and Shorthill, 1966; Linsky, 1973; Shorthill, 1973; Ulich et al., 1974; Lawson et al., 2003). It has been established that the infrared temperature curve during lunation is symmetrical with respect to a full moon, whereas the microwave temperatures exhibit a phase lag of several days and asymmetry with respect to the maximum temperature (e.g. Kamenskaya et al., 1965; Ulich et al., 1974). In the

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infrared wavelengths, the lunar surface temperature reaches a maximum of 400 K at full moon and falls below 110 K at new moon (Shorthill and Saari, 1965; Welch et al., 1965; Rusch et al., 1969; Monstein, 2001; Jianqing et al., 2010; Maghrabi, 2014). On the other hand, microwave observations showed that maximum temperatures varied between 290 and 260 K and minimum temperatures between 220 and 170 K, depending on the wavelength used (e.g. Drake, 1965; Monstein, 2001).

A total lunar eclipse is an important phenomenon that provides researchers with useful information about the moon's upper layers and allows them to model the thermal behavior of its surface (Fountain et al., 1976; Shaw, 1999; Jianqing et al., 2010). In the last 30 years few ground-based observations have been conducted to study the lunar properties during lunation and eclipse. In our previous work (Maghrabi, 2014) we studied the moon's temperature during lunation.

In this study, infrared measurements of the lunar temperature were carried out during the total lunar eclipse of 15th June 2011, which was totally visible in our location (Fig. 1a).

For this eclipse the penumbral phase started at 17:25 UT and the partial phase at 18:22 UT. At 19:22 UT the total eclipse began and the eclipse reached its greatest point at 20:12 UT. The totality and the partial eclipse ended at 21:02 UT and 22:02 UT, respectively. The penumbral eclipse ended at 23:00:41 UT (Fig. 1b). This central lunar eclipse was one of the darkest eclipses this century, second only to the total lunar eclipse on 16th July 2000. Fig. 2 shows four images taken by our Nikon D300 DSLR camera during different phases of the eclipse.

2. Instrumentation and methodology

The lunar observations were carried out using a single-channel infrared radiometer operating at a wavelength of 8–14 μm with a 3° field of view. The detector's output was calibrated on a black-body of known temperature and its performance was tested under various atmospheric conditions and showed a reliable and stable performance (Maghrabi et al., 2009). The design concept, construction and calibration processes, as well as the operating principle, have been described in detail in several papers (see, for example, Clay et al., 1998; Maghrabi et al., 2009).

The observations were made at the KACST observatory located in (lat. 21.25 N; long. 49.30 E) Jeddah, Saudi Arabia. Clear weather conditions prevailed during the observation night, when variations in both temperature and relative humidity were within 3 °C and 9%, respectively (Fig. 3). The observations were made from 18:00 LT on the 15th to 04:00 on the 16th. Hence, we were able to observe the complete eclipse.

The procedure for carrying out the measurements was as follows. The detector was mounted on the focal plane of an 8-inch telescope and the system (telescope-detector) was pointed towards the moon and remained for about 20 s. A longer exposure time was avoided to prevent any saturation in the infrared radiometer caused by long exposure to moonlight. The system was then moved by about three degrees above or below the disk of the moon to measure the atmospheric background. This procedure was repeated every five to ten minutes.

Forty-nine data points were taken during the night of the eclipse. Of these 49 observations, eight were made at the first penumbral stage, nine during the first partial stage, eleven during totality, thirteen during the second partial stage, and eight during the concluding penumbral stage.

The radiometer outputs were converted to moon temperatures using the radiation-balance equation as follows (Maghrabi et al., 2009; Maghrabi, 2014):

$$T_T = \sqrt[4]{\frac{V 2\pi d^2}{R\sigma A_T A_D} + T_D^4} \quad (1)$$

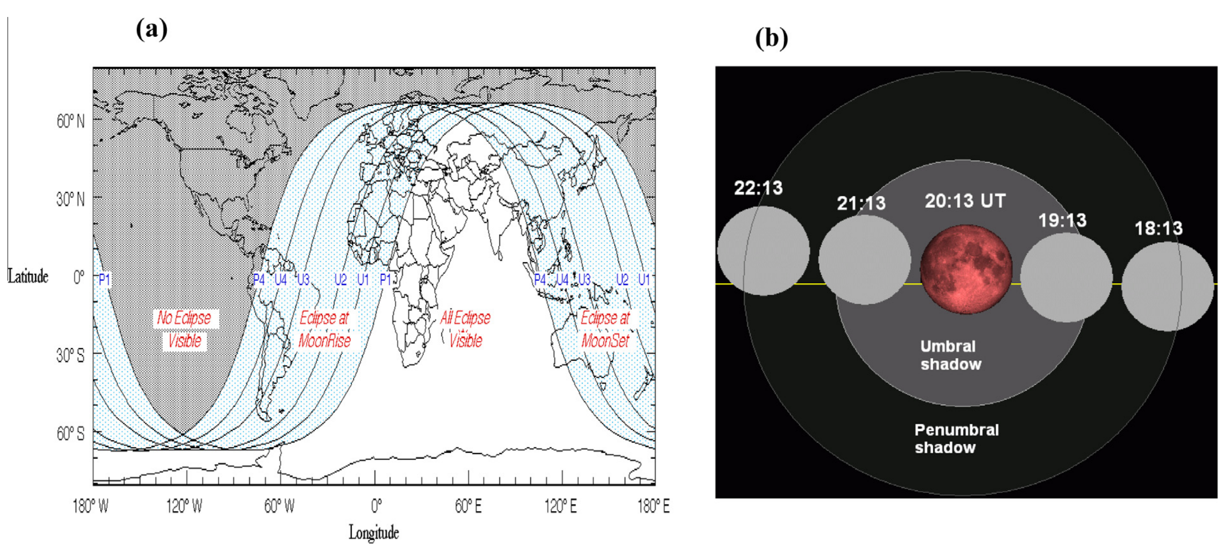

Fig. 1. (a) The visibility map for the 15th June 2011 lunar eclipse shows that all of the eclipse was visible from our site. (b) Shows the moon passing right to left through the Earth's shadow. Adapted from https://en.wikipedia.org/wiki/June_2011_lunar_eclipse.