MULTIWAVELENGTH OBSERVATIONS OF THE LUNAR ECLIPSE ON JANUARY 21, 2019 FROM SPACE. M. Shu, S. B. Wen, W. Cai, T.Y. Xu, and Y. Z. Wu. 1Key Laboratory of Planetary Sciences, Purple Mountain Observatory, Chinese Academy of Sciences, Nanjing, 210023, China (Minshu@pmo.ac.cn), 2School of Astronomy and Space Science, University of Science and Technology of China, Hefei, 230026, China, 3College of Geo-exploration Science and Technology, Jilin University Changchun, 130012, China, 4Space Science Institute, Macau University of Science and Technology, Macau, 999078, China.

Introduction: Lunar eclipses have consistently captivated human interest, spanning both historical and contemporary periods. Beyond their role as captivating astronomical events, lunar eclipses present unique opportunities for multidisciplinary exploration, shedding light on diverse aspects including the Moon's geological structure, radiation, and Earth's atmospheric composition. During lunar eclipses, the observation of Earthshine off the Moon facilitates the acquisition of transmission spectra, yielding insights into Earth's atmospheric composition [1][2]. Anthony has presented a lunar eclipse model that successfully elucidates the observed brightness, color phenomena, and the enlargement of the umbra [3]. Sébastien derived a time series of stratospheric turbidity from contemporary reports of total lunar eclipses, contributing to the exploration of eruption-induced climatic changes [4].

On January 21, 2019, a total lunar eclipse, famously referred to as the super blood wolf Moon, unfolded [5]. The celestial event began with the first penumbral con-tact at 02:36:30 UT (P1), followed by the onset of the partial eclipse nearly an hour later, marked by the first umbral contact at 03:33:54 UT (U1). Between 04:41:17 UT (U2) and 05:43:16 UT (U3), the Moon remained totally inside the umbra. The second partial phase ended at 06:50:39 UT (U4) and finally the Moon exit the penumbral shadow at 07:48:00 UT (P4).

Largely, studies on lunar eclipses were predominantly grounded in measurements affected by the Earth’s atmosphere. However, space-based observations effectively mitigate atmospheric interference, providing an extraordinary dataset for lunar eclipse research. This work is the first one to observe the lunar eclipse using remote sensing data from a geostationary Earth-orbiting satellite, Gaofen-4 (GF4). Our goal is to quantitatively characterize the spectral and radiative changes within the visible and near-infrared wavelength ranges during the lunar eclipse on January 21, 2019. It is anticipated that this study will inspire further endeavors in lunar eclipse observations from space, contributing to the enhanced development of the classical theory of lunar eclipses.

Data Description: The geostationary Earth imaging satellite GF-4 monitored the 2019 lunar eclipse in multiple bands. GF-4 has facilitated the acquisition of high-resolution full-disk images of the Moon across five visible and near-infrared (VNIR) bands, along with one mid-infrared band [6]. The VNIR detector on GF-4 has a 0.8° × 0.8° field of view, employing a CMOS image sensor with a 10240 × 10240 pixel array. This configuration results in a spatial resolution for lunar imagery of approximately ~500 m/pixel. The five VNIR bands, denoted as B1 to B5, encompass a panchromatic band (B1) and bands for blue, green, red, and near-infrared wavelengths (B2 to B5, respectively). Lunar eclipse data captured by GF-4's spectral bands B2 to B5 with effective wavelengths of 491.17 nm, 560.58 nm, 653.53 nm, and 809.43 nm were used in this study. These measurements allow for investigating photometric variations during lunar eclipses.

![Fig. 1 Exemplar lunar images in B2 during the lunar eclipse on January 21, 2019, captured with a 30 ms exposure time.](image)

Fig. 1 presents a thumbnail view of the Moon captured using GF-4 B2. The Earth's penumbral shadow is so faint that discernible changes in the Moon's brightness are not evident to the naked eye until the penumbra encompasses approximately 70% of the lunar disk. The GF-4 image acquired at 03:10 UT reveals that the brightness of the Moon's left-hand limb has diminished to 40% of its original brightness.
Correspondingly, the lunar image acquired at 07:20 UT, nearing the end of the eclipse, illustrates that the brightness of the Moon’s right-hand limb has attenuated to one-half of its original brightness.

Results and Discussion: The results of the measurements are given in Fig. 2, which displays the curve of irradiance at the standard distances (a Sun-Moon distance of 1 AU and a viewer-Moon distance of 384,400 km) versus universal time. Our measurements commenced at 2:30 UT, six minutes prior to the onset of the lunar eclipse, and concluded at 7:20 UT, 28 minutes before the eclipse's termination. This timeframe offers a partial coverage of the entire eclipse duration.

At 2:40 UT, the Moon had recently entered the penumbral shadow, manifesting a subtle increase in lunar irradiance. A parallel occurrence was also observed in studies by Dvorak (2005) [7] and Birriel (2019) [8]. While Dvorak (2005) elucidated the reasons behind this phenomenon, practical evidence supporting their explanation was not provided. Dividing the eclipse irradiance by the uneclipsed irradiance at the corresponding phase angle with the lunar photometric model reduced or eliminated the impact of the phase effectively, as shown in Fig. 3. We can fairly conclude that the increase in lunar brightness due to the opposing effect can be considered more substantial than the attenuation caused by Earth's obstruction. As the lunar surface area entering Earth's limb expands around 3:00 UT, despite the ongoing reduction in the phase angle, the impact does not appear substantial enough to counterbalance the influence of Earth obstructing sunlight. The lunar irradiance progressively decreased until the Moon completely entered the umbra after 4:30 UT, marking a point where the Moon's brightness was approximately 0.1% of that observed during the uneclipsed phase. During the total lunar eclipse, insufficient consideration of the faintness of the lunar brightness when it is fully immersed in the umbra led to a lack of long exposure, resulting in observational data gaps. The lunar irradiance started increasing as the Moon exited the umbra at 6:00 UT and progressed into the brighter outer region of the penumbra.

![Fig. 2 Disk-integrated irradiance at the standard distances during the lunar eclipse on January 21, 2019.](image)

![Fig. 3 Normalized relative irradiance of the entire lunar disc for B5 of GF-4.](image)

It is evident that the gradient of the light-change curve remains relatively stable at the boundary between the penumbra and the umbra. This can be attributed to the indistinct nature of the transition between the penumbra and the umbra, resulting in a gradual impact on the moon's brightness. This observation aligns with findings from the photometric observation of the October 2004 lunar eclipse [7].

This study represents a tentative step towards filling a gap in observations of full-disk lunar eclipse photometry from space. It also marks the inaugural exploration of lunar irradiance during a lunar eclipse using earth-orbiting satellite. Consequently, it is imperative to meticulously consider exposure time, time resolution, and spectral resolution in future lunar eclipse observations from space. Such considerations may significantly contribute to advancing research on lunar geological features, Earth's atmosphere, optical phenomena, and related areas.

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