Celestial mechanics and imaging polarimetry of the Kordylewski dust cloud around the Lagrange point L_5 of the Earth-Moon system

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Based on the following two papers:

Judit Slíz-Balogh, András Barta, Gábor Horváth (2018) Celestial mechanics and polarization optics of the Kordylewski dust cloud in the Earth-Moon Lagrange point L_5. Part I.: 3D celestial mechanical modeling of dust cloud formation. *Monthly Notices of the Royal Astronomical Society* 480 (4): 5550-5559 (doi: 10.1093/mnras/sty2049)

Judit Slíz-Balogh, András Barta, Gábor Horváth (2019) Celestial mechanics and polarization optics of the Kordylewski dust cloud in the Earth-Moon Lagrange point L_5. Part II.: Imaging polarimetric observation: new evidence for the existence of Kordylewski dust cloud. *Monthly Notices of the Royal Astronomical Society* 482 (1): 762-770 (doi: 10.1093/mnras/sty2630)

Introduction

In 1767 Euler discovered three unstable collinear points (L_1, L_2, L_3) and in 1772 Lagrange found two triangular points (L_4, L_5) in the gravitational field of two bodies moving under the sole influence of mutual gravitational forces (Szebehely 1967). In the three-body problem of celestial mechanics the L_4 and L_5 Lagrange points are stable in linear approximation, if the mass ratio $Q = m_{smaller}/(m_{larger} + m_{smaller})$ of the two primaries is smaller than $Q^* = 0.0385$ (Murray & Dermott 1999).

Astronomers found a large number of minor celestial bodies around these points of the planets of our Solar System and the Sun. The most well-known are the Greek and Trojan minor planets around the L_4 and L_5 points of the Sun-Jupiter system (Schwarz et al. 2015, Schwarz & Dvorak 2012). Minor planets have also been found around the triangular Lagrange points of the Sun-Earth (John et al. 2015), Sun-Mars (Christou 2017) and Sun-Neptune systems (Sheppard & Trujillo 2006).

What about the vicinities of the Lagrange points L_4 and L_5 of the Earth and Moon? Since the mass ratio $Q = m_{Moon}/(m_{Earth} + m_{Moon})$ $= 0.0123$ of the Moon and Earth is smaller than $Q^* = 0.0385$, the L_4 and L_5 points are theoretically stable. Thus, interplanetary particles with appropriate velocities could be trapped by them. In spite of this fact, they may be empty due to the gravitational perturbation of the Sun. Taking into account the perturbation of the Sun, the orbits in the vicinity of the L_5 point have been computationally investigated in two dimensions (Slíz et al. 2015, 2017). According to the results of these simulations, if test particles start from the vicinity of the L_5 point, their motion will be chaotic. This chaos is transient, and there are many trajectories which do not leave the system even for 106 days, and long-existing (for 30-50 years) islands form around L_5. Thus, although the gravitational perturbation of the Sun really sweeps out many trajectories from the L_5 point on an astronomical time scale, on a shorter time scale there are many long-existing trajectories too.

In 1961 Kordylewski found two bright patches near the L_5 point, which may refer to an accumulation of dust particles (Kordylewski 1961). Since that time this hypothetic formation is called the Kordylewski dust cloud (KDC). Until now only a very few computer simulations studied the formation and characteristics of the KDC (Slíz et al. 2015, 2017, Salnikova et al. 2018). To fill this gap, we investigated a three-dimensional four-body problem consisting of three massive bodies, the Sun, the Earth and the Moon (primaries) and a low-mass test (dust) particle, 1860000 times separately. Our aim was to map the size and shape of the conglomeration of particles not escaped from the system sooner than 3650 days around L_5.

In astronomy, the majority of knowledge originates from information obtained via light. Although light is a transversely polarized electromagnetic wave (Azzam & Bashara 1992), astronomical information is collected mainly with telescopes detecting only the spectrum (radiance and color) of the light of celestial objects within a limited wavelength range without polarization. Due to the polarization insensitivity of the majority of telescope detectors, valuable astronomical information remains unrevealed/undetected.

Fortunately, a few telescopes are mounted with linear and/or circular polarizers and can also measure the polarization characteristics of light of distant celestial objects, not just their spectrum. The nearest celestial phenomenon of semi-astronomical importance is the unpolarized (polarizationally neutral) points of the Earth's atmosphere, namely the Arago's, Babinet's, Brewster's and the fourth neutral points observed first in 1809 (Arago 1811), 1840 (Babinet 1840), 1842 (Brewster 1842, 1847) and 2001 (Horváth et al. 2002). Nowadays these celestial points are studied with imaging polarimetry, a very useful technique to gather information from spatially extended phenomena in the optical environment (Horváth & Varjú 2004; Horváth 2014). Farther targets of astronomical imaging polarimetry are the Sun, its planets and their moons in the Solar System (Gehrels 1974; Können 1985; Belskaya et al. 2012). Although the direct sunlight is unpolarized, the solar corona is partially polarized due to Compton scattering on the electrons of the Sun's atmosphere (Können 1985). The polarization pattern of the solar corona can be measured, if the bright Sun's disc is artificially occluded by an opaque disc, or when the Moon occludes it during total solar eclipses (Können 1985; Horváth & Varjú 2004). Planets and moons reflect partially polarized light, from the polarization characteristics of which certain surface features can be revealed that would be hidden for polarization-blind telescopes. Much farther targets are various stars, comets, galaxies and nebulae, the light of which is originally more or less polarized or becomes polarized due to interstellar and intergalactic magnetic fields (Gehrels 1974; Marin et al. 2012; Hadamcik et al. 2014; Reig et al. 2014; Ivanova et al. 2015; Marin et al. 2015; Zejmo et al. 2017).

Results

In special cases there are exact well-known classic analytical solutions of the three-body problem (Szebehely 1967, Rajnai et al. 2014). Recently, a new exact solution of a special case of the four-body problem was discovered (Érdi & Czirják 2017). However, the general and especially the three-dimensional four-body problem can be solved only numerically.

The stability of the L_4 and L_5 Lagrange points of the Earth and the Moon has some well-exploitable advantages: They are suitable for spacecraft, satellite or space telescope parking with minimal fuel consumption (nonetheless at the moment there are no spacecraft orbiting neither at L_4 nor at L_5 in the Solar System), or they can be applied as transfer stations for the mission to Mars or other planets, and/or to the interplanetary superhighway. The investigation of the dynamics of the Earth-Moon Lagrange points is important as well from the point of view of space navigation safety. Since in the study of these points the gravitational effect of the Sun cannot be ignored, one has to study computationally a four-body problem, as we have done.

Figure 1 depicts well the size and shape of the dust cloud, but it does not give any information about the particle density. Therefore we created images of the dust cloud (Figure 2) where the picture area is uniformly divided into cells in the line of sight, and these cells are shaded with different gray hues depending on the number of particles in the cells. The structure of the dust cloud (Figure 2A) consists of two distinct parts: (i) an extended, less dense banded conglomeration (Figure 2B), and (ii) an elongated denser one (Figure 2C). The length of the bands of a particular dust cloud varies periodically (synchronous with the Moon's orbital period) depending on how many days earlier the particles were trapped. After being trapped, the particular dust cloud begins to contract in the band direction, and about 6-7 days later its length is minimal and its density is maximal. Then it starts to expand again, and reaches its maximal length after about other 6-7 days. If the trapping happens 6, 7, 19 or 20 days earlier, the elongated and dense particular clouds will dominate (Figures 2A and 2C). If about 6, 7, 19 or 20 days earlier there was not trapping, the dust cloud will look like shown in Figure 2B.

Our simulations assumed steadily discontinuous material capture. But in reality it is far from being so. For example, in the case of a meteor shower the amount of trapped particles is larger, while at other times it may be much smaller. So the bands in Figure 2, which are the results of trappings of different days earlier with different velocities, are not always and all present. Some bands may be missing, others are more or less dense. The shape and structure of a dust cloud vary in a relatively short time, and depend on the trapping date and the size of its particular dust clouds.

The two kinds of the dust clouds seen in Figures 2B and 2C show

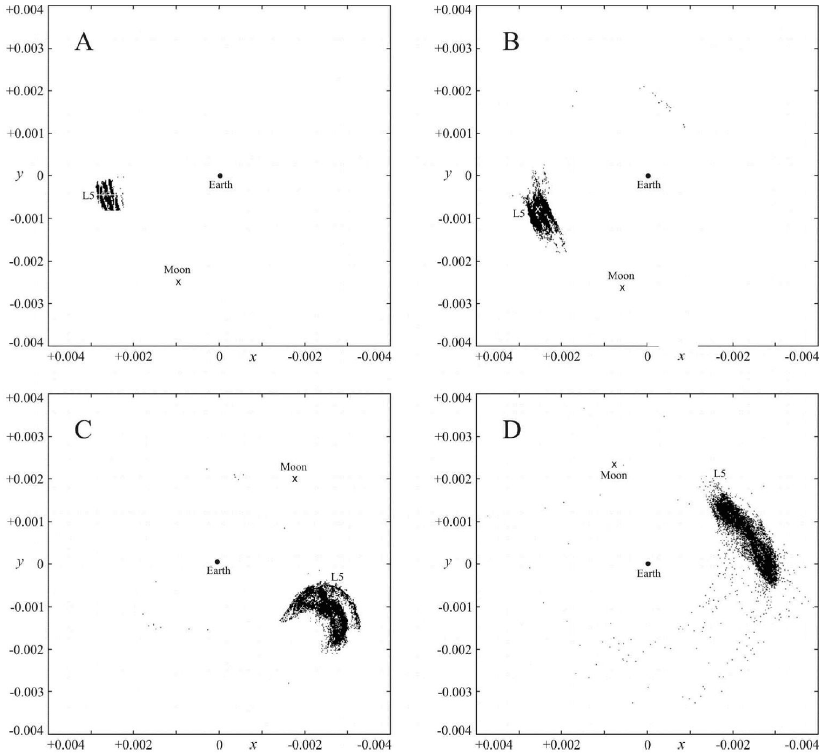

Figure 1. (A) Initial positions (black pixels) of the trajectories of 1860000 particles non-escaped sooner than 3650 days, started at t_0 = 01:14 (UT) on 22 August 2007 from the vicinity of the L_5 point in geocentric ecliptic coordinate system. (B-D) The positions (black pixels) of these particles after 28 (B), 1460 (C) and 3650 days (D). Earth: dot (center of the picture), L_5 point: $\times$, Moon: $\times$. A given black pixel means that in that direction of view there is at least one particle.

an interesting match with the two types of *Gegenschein* described by (Moulton 1900): (i) a large and round (Figure 2B), or (ii) a very much elongated (Figure 2C), varying in a few days time scale, similarly to our simulations.

Our simulations showed that the dust particles trapped earlier than 20-25 days do not contribute to the dust cloud's structure, because after that time the dust is smoothly distributed. This also means that if we see bands, they are the results of trappings not earlier than 20-25 days.

We assume that our simulated particle conglomeration around the L_5 point (Figure 2) corresponds to the dust cloud photographed by Kordylewski (1961). Salnikova et al. (2018) presented another computer model of the dust cloud formation around L_5, and they also concluded that the accumulation of dust particles is indeed possible around L_5.

The observation of the KDC with imaging polarimetry is much reliable than that with photometry. Thus, it is imaginable that the KDC did not reveal itself in the infrared patterns measured by IRAS (https:

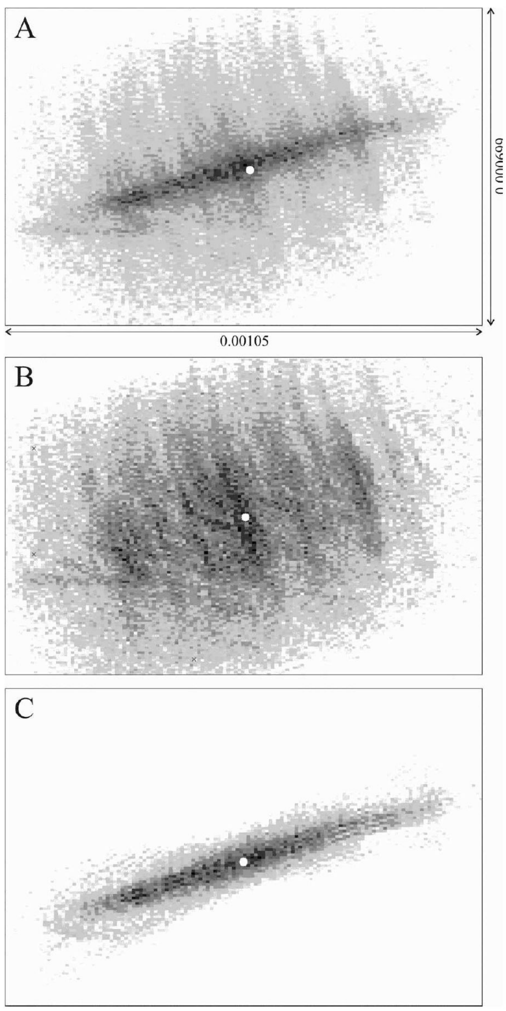

Figure 2. Computer-simulated density distribution of the particles of the KDC around the L_5 point (white dot) of the Earth-Moon system in equatorial coordinate system as we would see in the sky. The angular extension of the picture is $22^\circ.5$ (horizontal) $\times$ 15° (vertical). The horizontal and vertical axis denotes the direction of the right ascension (RA) and the declination (DE), respectively. (A) The dust cloud (at target date 01:14 on 19 August 2017) of the particles which were trapped 1-28 days earlier. (B) As (A) the dust cloud, the particles of which were trapped 1-5, 8-18 and 21-28 days earlier. (C) As (A) for the dust clouds, the particles of which were trapped 6, 7, 19 and 20 days earlier. The darker the gray shade, the larger is the particle density.

//lambda.gsfc.nasa.gov/product/iras/docs/exp.sup/toc.html) and COBE (https://science.nasa.gov/missions/cobe), especially if astronomers did not search it directly. Furthermore, since longer wavelengths are scattered less than shorter ones, the photometric detection of the KDC is more difficult in the infrared than in the visible spectral range. Finally, the lack of photometric detection of the KDC by earlier astronomical missions (e.g. IRAS, COBE) does not exclude at all the existence of this dust cloud detected by us with imaging polarimetry (Slíz-Balogh, Barta, Horváth 2018). Note that the major aim of all earlier photometric missions was quite different than the detection of the KDC. If during the evaluation of the registered photometric patterns of these missions researchers did not look directly for the KDC, then the chance of its detection was considerably reduced, if not zero.

Similar happened with the detection of the 4th polarizationally neutral point of the Earth atmosphere: The existence of this neutral point was predicted by David Brewster in the 1840s, after his discovery of the 3rd neutral point, named after its first observer, Brewster (1842). However, the 4th neutral point can be observed only from higher altitudes ($>$ 1 km from the Earth surface), which limitation made difficult such an observation. Thus, the first scientifically documented observation of the 4th neutral point happened only in 2002 (Horváth et al. 2002). Interestingly, in 2002 the satellite-born imaging polarimeter, called POLDER (Deschamps et al. 1994) was already registering the polarization patterns of earth light for several years. The polarization traces of the 4th neutral point should also exist in the polarimetric data of the POLDER mission. In spite of this, POLDER researchers did not recognize the 4th neutral point, because they did not seek it; they were interested in quite other aspects and meteorological applications of the POLDER-measured polarization data. However, if POLDER researchers have looked for the 4th neutral point, they surely would have found it in their polarization patterns measured from the high altitude of the POLDER satellite, as Horváth et al. (2002) found it in their polarization patterns measured from 3.5 km from a hot air balloon.

Theoretically, there are extended small-concentration particle clouds around the L_4 and L_5 Lagrange points of the Earth-Moon system. Although the first mention of the possible accumulation of the zodiacal dust near the L2 point of the Sun-Earth system goes back to Moulton (1900), Kordylewski (1961) was the first to photograph two faint patches near the L_5 point from the Polish mountain Kasprowy Wierch between 6 March and 6 April 1961. During his observation time, these patches with an angular diameter of about 6° were slightly displaced relative to the L_5 point. Since that time, these patches are believed by some scientists to be the KDCs. However, it is very difficult to detect the KDCs against the galactic light, star light, zodiacal light and sky glow (Roach 1975).

In spite of the pioneer observation by Kordylewski (1961) the existence of the KDCs is still under dispute, due to their extreme faintness making it difficult to confirm their existence. So far, there was no any convincing observational result, because the KDC is a very faint phenomenon, and it is also difficult to distinguish it from the even fainter zodiacal light. The latter is the sunlight scattered by the zodiacal dust. In the region of the anti solar point, the intensity of the zodiacal light is relatively enhanced, because each dust particle is seen in full phase. This phenomenon is the gegenschein (counter glow). So, it seems also the most convenient to photograph the KDC when it is near the anti solar point (full phase). However, in this case the polarization signature of the KDC is the weakest, consequently, its polarimetric study is the most difficult.

Over the past decades, some contradictory results have been achieved: Roosen (1966, 1968) found no evidence to the existence of KDCs near the L_4 and L_5 points. He suggested that if the KDCs exist at all, they are not associated with the Earth-Moon libration points. Wolff et al. (1967) did not find excess light in excess of 5% of the light of the neighboring night sky near the Lagrange points L_4 and L_5 of the Earth-Moon system, even though they photographed under astronomically favorable circumstances from an aircraft. However, Vanysek (1969) reported a successful visual observation (with naked eye of numerous persons) from an aircraft organized four times by NASA in 1966. The observers on that airplane described very faint nebulosities near the L_4 and L_5 points at large phase angles (at Vanysek (1969) the phase angle of the anti solar point is 180°). Vanysek (1969) proposed to detect the KDC during and shortly after the new-Moon phase, at small phase angles because of the strong forward scattering of sunlight by cloud particles.

The KDC may be a transient phenomenon, because the L_4 and L_5 points might be unstable due to perturbations of the Sun, solar wind and other planets, as many astronomers believe. According to our computer simulations, the KDC has a continuously changing, pulsing and whirling shape, furthermore, the probability of dust particles being trapped is random due to the occasional incoming of particles and their incidental velocity vectors. Therefore, the structure and particle density of the KDC is not constant. The above-mentioned contradicting photometrical observations (Kordylewski 1961; Roosen 1966, 1968; Wolff et al. 1967; Vanysek 1969) also hint at the possible transient feature of the KDC.

However, at a lunar eclipse the KDC could not be observed at all (Bruman 1969). A photographic search (Valdes & Freitas 1983) did not find any objects at the Earth-Moon Lagrange points L_4 and L_5. The limiting magnitude for the detection of libration objects near L_4 and L_5

was 17-19th magnitude. Thus, this survey was not sensitive enough to detect such diffuse clouds such as the KDCs. The Japanese Hiten space probe (using the Munich Dust Counter, an impact ionization detector designed to determine mass and velocity of cosmic dust) has passed through the L_4 and L_5 points of the Earth and Moon system, but did not find an obvious increase in dust concentration compared to the surrounding space (Igenbergs et al. 2012).

In spite of these negative results, there are, however, some positive reports about the photometric observations of the KDC. Analyzing the data from the Rutgers OSO-6 Zodiacal Light Analyzer experiment, Roach (1975) concluded that these dust clouds do exist in the L_4 and L_5 points, their angular size is about 6° as seen from the Earth, and they move around the libration points. Using a number of parallel cameras at the observing station Roztoki Górne, Winiarski (1989) determined that the colors of the dust clouds near the L_4 and L_5 points differ from those of the counter glow (gegenschein), which means that the dust particles constituting them are also different.

According to our computer simulations, the KDC around the Lagrange point L_5 of the Earth-Moon system is a dynamic structure with inhomogeneous, temporally changing particle density composed of several particle clusters. Since this dust cloud is illuminated by direct sunlight, the faint light scattered from the dust particles can be observed and photographed from the Earth surface with appropriately radiance-sensitive detectors. Such a pioneer photographical documentation has been first performed by Kordylewski (1961). According to the other above-mentioned successful trials (Vanysek 1969; Roach 1975; Winiarski 1989), the KDC can be visually detected only from small phase angles (determined by the observer, the Sun and the L_4/L_5 point), i.e. at or near "full dust moon". In this case the degree of polarization p of dust-scattered sunlight is minimal, practically zero. Since at phase angles near to 90° the p of dust-scattered sunlight is maximal, it gives us the best chance to polarimetrically detect the KDC under this condition. Using imaging polarimetry, we indeed detected the polarization signature of the KDC in the L_5 point of the Earth and Moon (Figures 3 and 4). Furthermore, the faint light scattered by the KDC can also be discerned in the color photographs and the patterns of radiance I measured by us in the red, green and blue spectral ranges (Figure 3 and 4). Theoretically, dust-scattered sunlight becomes partially linearly polarized with the direction of polarization perpendicular to the scattering plane determined by the Sun, the ground-born observer and the dust region observed

(Können 1985; Coulson 1988; Collett 1994). We have indeed found this forecasted characteristic in the patterns of the angle of polarization measured with imaging polarimetry (Figures 4 and 7). This is one of the strongest proof that we observed a sunlit light-scattering object outside the Earth's atmosphere, rather than a terrestrial phenomenon. A further fact supporting the observation of the KDC is that in the measured α-patterns several clusters occur, as our simulations suggest (Slíz-Balogh et al. 2018).

Theoretically, the closer the angle of scattering is to 90°, the higher the degree of polarization p is of scattered light. We really found that the p-values of the KDC observed at 01:14:15 UT on 19 August 2017 with 87°.3 phase angle are higher than those observed at 23:29:67 UT on 17 August 2017 with 73° phase angle (Figures 3A,B and 4A,B). This is further convincing evidence that we registered the KDC with imaging polarimetry, rather than another phenomenon.

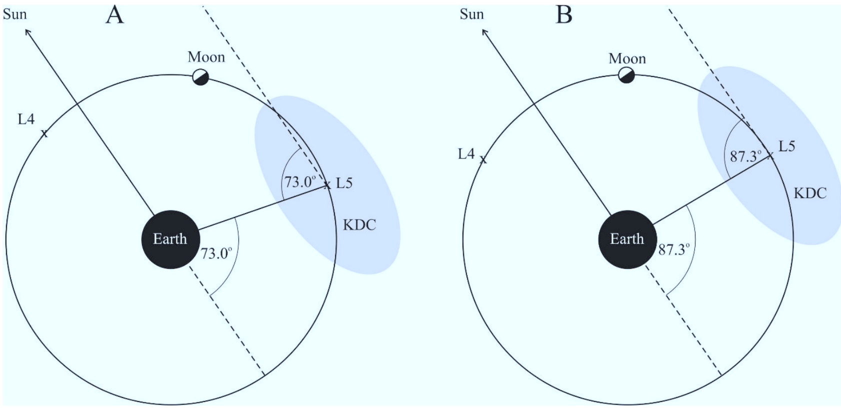

Figure 3. Positions of the Moon and the L_5 Lagrange point of the Earth-Moon system in the plane of the Moon's orbit on 17 August 2017 at 23:29:67 UT with 73°.0 phase angle (A), and on 19 August 2017 at 01:14:15 UT with 87°.3 phase angle (B). Apart from the Earth and Moon, the relative dimensions are not to scale. The Sun's direction is indicated by an arrow. KDC: Kordylewski dust cloud.

In order to exclude the possibility that with our polarization-sensitive telescope we registered an artificial optical phenomenon rather than the KDC we performed control measurements. We could imagine only the following three artifact possibilities:

- Unwanted ambient lights from the immediate optical environment reflected within our telescope from certain mechanical and/or optical elements.
- A thin cloud covered the sky region studied.

- Condensation trails of an airplane occurred within the field of view of our telescope.

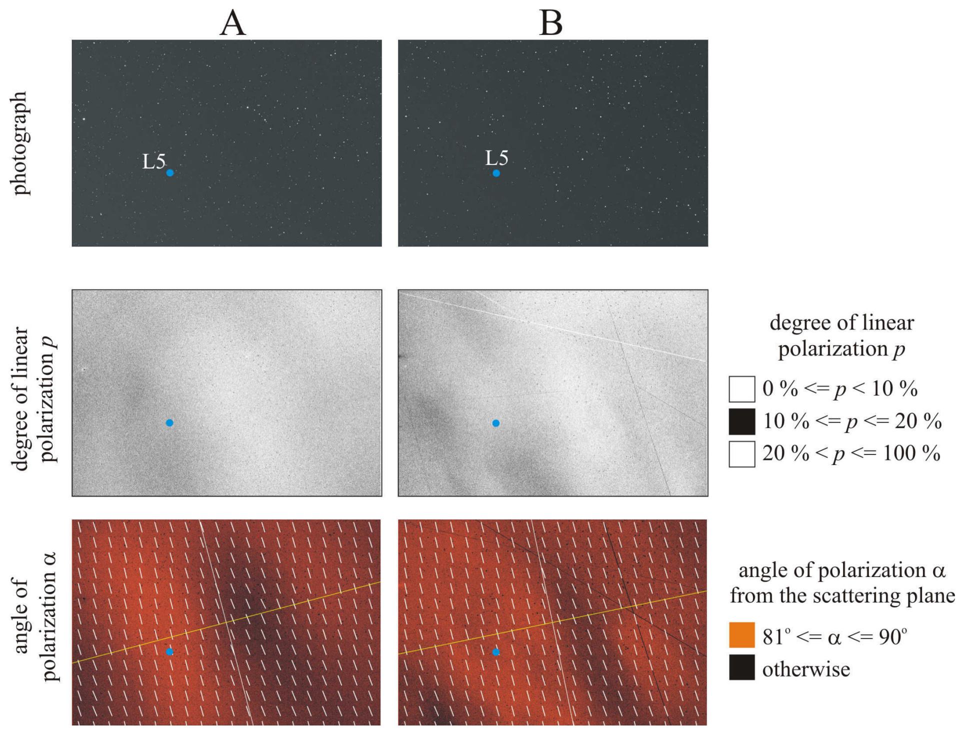

FIGURE 4. (A) Color photograph, and patterns of radiance I, degree of linear polarization p and angle of polarization α (clockwise from the scattering plane) of the sky around the L_5 Lagrange point of the Earth-Moon system measured by imaging polarimetry in the green (550 nm) spectral range at 23:29:67 UT on 17 August 2017 (picture center: RA = $2^h12^m28^s.2$, DE = $8°3'52''.6$) (A), and at 01:14:15 UT on 19 August 2017 (RA = $3^h11^m23^s.36$, DE = $12°21'5''.38$) (B). The position of the L_5 point is shown by a blue dot. In the α-patterns the short white bars represent the local directions of polarization, while the long yellow and white straight lines show the scattering plane and the perpendicular plane passing through the center of the picture, respectively. The Kordylewski dust cloud is visible in both the p-pattern (clusters of black pixels with $10\% \leqslant p \leqslant 20\%$) and the α-pattern (red pixels with $81° \leqslant \alpha \leqslant 90°$). The I-, p- and α-patterns are very similar in the red (650 nm) and blue (450 nm) spectral ranges. Apart from the perpendicular white and yellow straight lines, the straight tilted lines in the p- and α-patterns of the B slides are traces of satellites.

The question may also arise whether the volume concentration of the KDC's particles is large enough to be detected on the ground. Due to the trapping effect of the Lagrange point L_5, the particle density of the KDC should be greater than that of the surrounding zodiacal dust. If the latter has been photometrically observed from the ground, it means that the former is also detectable optically (photometrically and/ or polarimetrically). The first evidence for the existence of the zodiacal dust and its band-structure was provided by the Infrared Astronomical

Satellite (IRAS), while its first ground-based photometric observation was performed in 1997 by Ishiguro et al. (1999). They detected five very faint zodiacal bands, and emphasized that the ground-based photometry of the zodiacal light by a cooled CCD camera enabled them to investigate the structure and the temporary changes of these dust bands.

All ground-based observing systems are confronted with the light pollution of man made ground-born light sources. These artificial lights usually increase the degree of linear polarization of skylight due to atmospheric aerosols (Kyba et al. 2011). Shkuratov et al. (2007), Kocifaj (2008) and Kocifaj et al. (2008) investigated the optical properties of these aerosol particles and their effect on light polarization. The photometric and polarimetric laboratory measurements of different surfaces and aerosol particles performed by Shkuratov et al. (2007) demonstrated the so-called negative polarization induced by the multiple scattering of light on rough surfaces and aerosols. Kocifaj et al. (2008) examined and compared the linear polarization of light scattered by homogeneous-sphere particles and Gaussian-core particles. Kocifaj (2008) carried out light pollution simulations and concluded that the role of ground-based light sources in light pollution is considerably enhanced under overcast sky conditions. The location of our imaging polarimetric measurements (Badacsonytördemic, $17°28'15''$ E, $46°48'27''$ N) is far away from all major settlements and there were only some local minor point sources (lamps), which were the same for all measurements, including the control measurement (without the L_5 Lagrange point). Furthermore, during our measurements the sky was clear, cloudless. Thus, the effect of aerosol-induced light pollution on the measured polarization patterns was negligible during our measurements.

The direction of polarization of sky glow is perpendicular to the plane determined by the observer (polarimeter), the sky glowing celestial point observed and the ground-born light-polluting source (e.g. city lights). This direction is quite different from the measured direction of polarization of the KDC, which is perpendicular to the scattering plane (marked with a yellow straight line in Figure 4) determined by the observer (polarimeter), the Sun and the L_5 Lagrange point. Due to the minimal light pollution in our measurement site, a relevant contribution of sky glow to the measured polarization signature was out of question. A minimal sky glow could have appeared only near the horizon, but the field of view of our imaging polarimetric telescope was far from the horizon. Thus, sky glow effects were surely negligible.

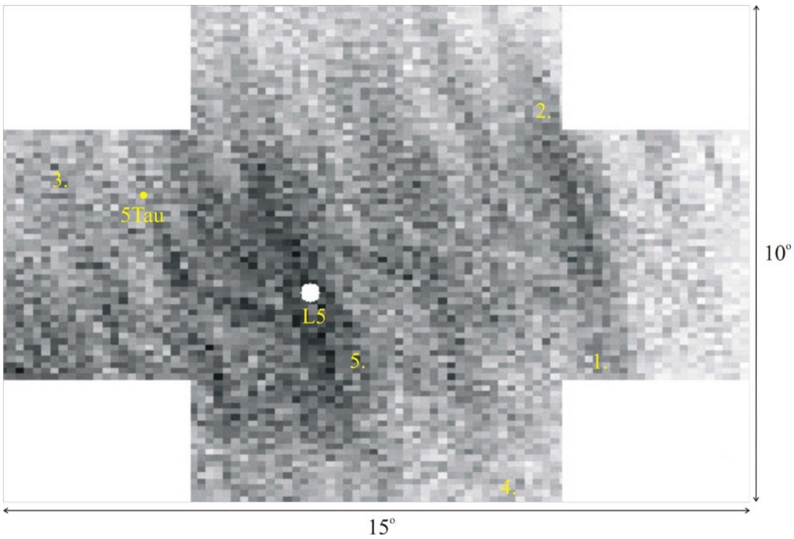

FIGURE 5. Computer-simulated volume density distribution of the particles of the KDC around the L_5 point (white dot) of the Earth-Moon system. The darker the gray shade, the larger is the particle density. The numbered windows correspond to the fields of view of our imaging polarimetric telescope with which the polarization patterns of the sky around L_5 were measured.

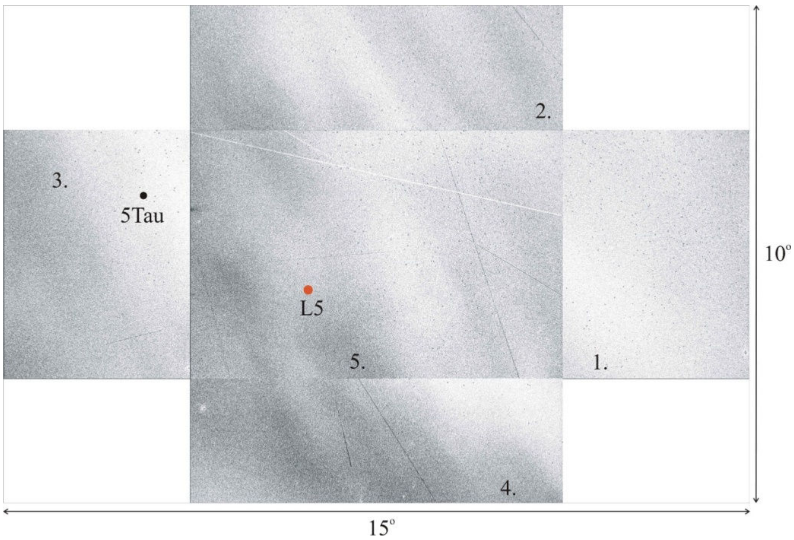

FIGURE 6. Mosaic pattern of the degree of linear polarization p of the KDC around the L_5 point (red dot) measured on 19 August 2017 in the green (550 nm) with imaging polarimetry. The mean time (UT) of the patterns are: (1) 00:03:34, (2) 00:26:51, (3) 00:50:25, (4) 01:02:26, (5) 01:14:15.

Figure 5 shows the computer-simulated volume density distribution of particles of the KDC around the L_5 point, where the numbered windows correspond to the fields of view of our imaging polarimetric telescope with which the polarization patterns of the sky around L_5 were measured.

Figures 6 and 7 display the mosaic patterns of the degree of polarization p and angle of polarization α of the KDC around L_5 measured in the green (550 nm) with imaging polarimetry on 19 August 2017. Comparing

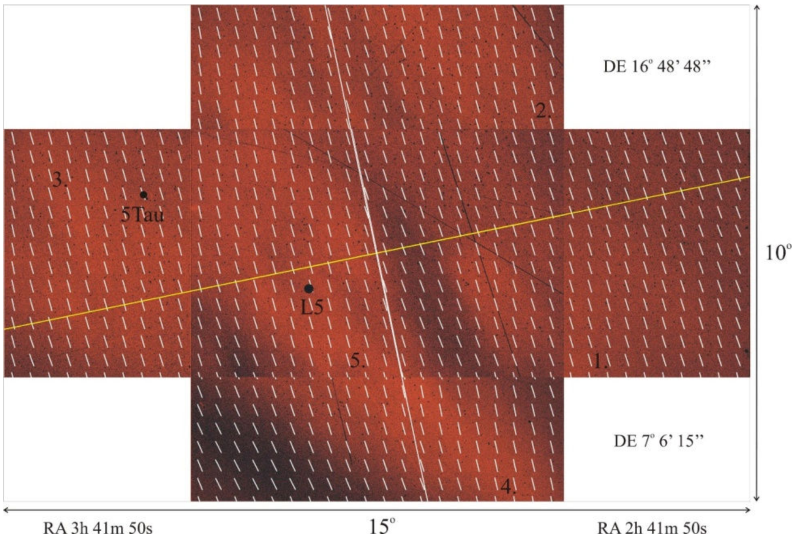

FIGURE 7. As Figure 6 for the angle of polarization α (clockwise from the scattering plane). The short white bars represent the local directions of polarization. The long yellow and white straight lines show the scattering plane and the perpendicular plane passing through the center of the picture, respectively.

the simulated particle density and the measured polarization patterns, a remarkable similarity can be seen: in all three patterns a multiparty structure occurs with several elongated clusters, showing that the KDC is a heterogeneous particle cluster. The polarization patterns of the different neighboring windows cannot be exactly fitted, because the sequential polarimetric measurements happened in slightly different points of time due to the necessary exposure (3×180 s), and during this short period the structure of the dynamic dust cloud slightly changed.

On the basis of the above arguments we conclude that for the first time we have observed and registered polarimetrically the Kordylewski dust cloud around the Lagrange point L_5 of the Earth and Moon. By this we corroborated the existence of the KDC first observed photometrically by Kordylewski (1961).

Similarly, to many objects and optical phenomena in nature, the knowledge of polarization characteristics can provide valuable additional information. Although the KDC can also be observed with radiance-sensitive devices, it can be registered easier and more effectively and studied by polarization-sensitive telescopes like our one. The observability of the KDC is different from that of the Arago, Babinet, Brewster and fourth neutral points of the atmosphere: these unpolarized celestial points cannot be seen at all in color photographs or radiance patterns measured in different spectral ranges, but can be observed and studied in the patterns of the degree and angle of polarization of skylight (Horváth et al. 2002).

In the future, it would also be worth studying both computationally and imaging polarimetrically the dynamical and optical characteristics of the KDC around the L_4 Lagrange point of the Earth-Moon system. It would be interesting to compare the features of the KDCs formed around the L_5 and L_4 points. For these tasks several polarization-blind astronomical telescopes should be mounted with imaging polarimetric devices composed of rotatable linear polarizers. One could also try to measure the circular polarization (if any) of the light scattered by the KDCs with an appropriate polarimeter.

The existence of the KDC suggests the challenging possibility that appropriate astronautical missions could take samples from the particles librating at and around the L_4 and L_5 points of the Earth and Moon. The investigation of these clouds could be important from the point of view of space navigation safety.

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