Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY

MNRAS **518,** 5236–5241 (2023) https://doi.org/10.1093/mnras/stac3429
Advance Access publication 2022 November 26

First polarimetric evidence of the existence of the Kordylewski Dust Cloud at the L4 Lagrange point of the Earth–Moon system

Judit Slíz-Balogh,[1,2,3]★ Attila Mádai,[1] Pál Sári,[1,4] András Barta[3,5] and Gábor Horváth [1,3]★

[1]*Astropolarimetry Research Group, Office of Supported Research Groups, Eötvös Loránd Research Network, H-1052 Budapest, Piarista utca 4, Hungary*
[2]*Department of Astronomy, ELTE Eötvös Loránd University, H-1117 Budapest, Pázmány sétány 1, Hungary*
[3]*Environmental Optics Laboratory, Department of Biological Physics, ELTE Eötvös Loránd University, H-1117 Budapest, Pázmány sétány 1, Hungary*
[4]*Fornax 2002 Ltd., H-2119 Pécel, Ady Endre utca 1, Hungary*
[5]*Estrato Research and Development Ltd., H-1124 Németvölgyi út 91/c, Budapest, Hungary*

Accepted 2022 November 18. Received 2022 November 3; in original form 2022 September 28

ABSTRACT

In 1961, Kordylewski found two bright patches near the L5 Lagrange point of the Earth–Moon system. This referred to an accumulation of dust particles, later called as Kordylewski dust cloud (KDC). In spite of the photographic observation of the L5 KDC by Kordylewski and its visual (naked-eyed) or photometric confirmation by others, some astronomers assumed that the KDC cannot exist, because the gravitational perturbation of the Sun may disrupt the stabilizing effect of the triangular Lagrange points L4 and L5 of the Earth and Moon. In 2017, the L5 KDC was observed in two consecutive nights by ground-based imaging polarimetry. So far the L5 KDC has been detected 16 times and the L4 KDC only 5 times. Contrary to the visually, photometrically, and polarimetrically documented existence of the L5 KDC, a polarimetric proof does not exist for the L4 KDC. On 2022 July 3, we were able to detect the polarization signals of the L4 KDC, furthermore on 2021 October 31 we detected polarimetrically again the L5 KDC. In this work, we present the first polarimetric evidence of the existence of the L4 KDC, and corroborate polarimetrically the existence of the L5 KDC for the third time.

Key words: celestial mechanics < Astrometry and celestial mechanics – polarization < Physical Data and Processes – Earth < Planetary Systems – Moon < Planetary Systems – instrumentation: polarimeters < Astronomical instrumentation, methods, and techniques – methods: observational < Astronomical instrumentation, methods, and techniques.

1 INTRODUCTION

In 1767, Leonhard Euler discovered the three unstable collinear points L1, L2, L3, and in 1772 Joseph-Louis Lagrange found the two triangular points L4, L5 in the gravitational field of two bodies moving under the sole influence of mutual gravitational forces (Szebehely 1967; Rajnai, Nagy & Érdi 2014). In the restricted three-body problem, the orbits around the L4 and L5 Lagrange points are stable, if the mass ratio $Q = m_{\rm smaller}/m_{\rm larger}$ of the two primary bodies is smaller than $Q* = 0.0400$ (Murray & Dermott 1999).

Since in the Earth–Moon system the mass ratio $Q = m_{\rm Moon}/m_{\rm Earth} = 0.0123$ is smaller than $Q* = 0.0400$, the L4 and L5 points are theoretically stable. Thus, interplanetary particles with appropriate speeds could be trapped by them. However, both points could also be empty because of the gravitational perturbation of the Sun. Taking into account the perturbation of the Sun, the orbits in the vicinity of the Earth–Moon L5 point have been computationally investigated in two (Slíz, Süli & Kovács 2015; Slíz, Kovács & Süli 2017; Salnikova, Stepanov & Shuvalova 2018) and three (Slíz-Balogh, Barta & Horváth 2018) dimensions. As far as we know, the influence of the small perturbation of Venus and/or giant planets on these orbits has not been taken into account in computer simulations. According to the results of these simulations, if test particles (with negligible mass relative to the two large bodies) start from the vicinity of the L5 point, their motion will be chaotic. This chaos is transient, and there are many particle trajectories which do not leave the system even for 10^6 d, and long-existing (for 30–50 yr) particle islands form around L5. Thus, although the solar gravitational perturbation sweeps out many particles from the vicinity of the L5 point on an astronomical time-scale, on a shorter time-scale there are many long-existing particle trajectories too around L5.

In 1961, Kazimierz Kordylewski found two bright patches near the Earth–Moon L5 point, which referred to an accumulation of dust particles (Kordylewski 1961). Since that time, this formation is called the Kordylewski dust cloud (KDC). In spite of the visual (naked-eyed) and photometric observations of the L5 KDC by Kordylewski (1961) and its photometric and/or visual confirmations by Simpson (1967), Vanysek (1969), Roach (1975), and Winiarski (1989), certain astronomers (Roosen 1966, 1968; Roosen, Harrington & Jeffreys 1967; Wolff, Dunkelman & Hanghney 1967; Bruman 1969; Valdes & Freitas 1983; Igenbergs et al. 2012) assumed that the KDC does not exist, because the gravitational perturbation of the Sun may disrupt the stabilizing effect of the L4 and L5 points of the Earth and Moon. Using ground-based imaging polarimetry, Slíz-Balogh, Barta & Horváth (2019) presented the first polarimeric evidence for the existence of the KDC around the L5 point of the Earth–Moon system. Furthermore, their polarimetric observations were supported by the results of their 3D computer simulations of particle cloud formation around the L5 point. Recently, Wang et al. (2021) reviewed

★ E-mail: judit.sliz@gmail.com (JS-B); gh@arago.elte.hu (GH)

the knowledge about the ground- and space-based observations of the KDCs.

So far, the L4 and L5 KDCs have been observed 19 times visually/photometrically and at 2 times polarimetrically. However, the L5 KDC has been detected 16 times, while the L4 KDC only 5 times. The reason for this three-times more frequent observation of the L5 KDC may be the varying (appropriate/inappropriate) sky and/or astronomical conditions during these observations. Recently, Slíz-Balogh et al. (2022) gave another possible physical reason for the asymmetric frequency of KDC observations. Performing computer simulations, they found that the L5 point can have by maximum 9 per cent larger particle capture than L4, depending on the date of observation. This asymmetry of particle capture can promote/advance the increase of particle density and polarized intensity of particle-scattered sunlight of the L5 KDC, which helps its more frequent observation compared to the L4 KDC.

Contrary to the visually, photometrically, and polarimetrically documented existence of the L5 KDC, a polarimetric proof does not exists for the L4 KDC: (i) On 1961 September 16, 17, and 18, Kordylewski (1961) detected the L4 KDC only with his naked eyes. (ii) Although during four NASA flights at an altitude of 12 000 m on 1966 March 1, 2, 10, and 12, astronomers onboard observed visually and photographically both the L4 and L5 KDCs (Simpson 1967; Vanysek 1969), convincing photometric data (series of isoluminance lines like that of Kordylewski 1961, or photographs) about the L4 KDC have never been published. Consequently, an evidence for the existence of the L4 KDC is still lacking.

To fill this gap, after the two polarimetric observations of the L5 KDC on 2017 August 17 and 18 (Slíz-Balogh et al. 2019), we continued our astropolarimetric study. As a result of this, on 2022 July 3 we were able to detect as first the polarization signals of the L4 KDC, and as a byproduct, on 2021 October 31 we detected polarimetrically again the L5 KDC. The aim of this work is to present the first polarimetric evidence of the existence of the L4 KDC, and to corroborate polarimetrically the existence of the L5 KDC for the third time.

2 METHOD

In the private observatory of Judit Slíz-Balogh (17º 28' 15' E, 46º 48' 27' N, Badacsonytördemic, Hungary), polarization pictures were taken (exposure: 180 s) about the L4 and L5 triangular Lagrange points of the Earth–Moon system and their surrounding of 7.5° (horizontal) × 5° (vertical) when the sky was cloudless and aerosolfree. The motor-driven German Equatorial Fornax 100 Telescope Mount was controlled with an accurate driving correction system (Telescope Drive Master). Further details of our rotating-analyser sequential imaging polarimetric telescope have been published by Slíz-Balogh et al. (2019).

3 RESULTS

Fig. 1 displays the polarization patterns of the L4 and L5 KDCs measured with imaging polarimetry in the green (550 nm) spectral range. The L4 KDC was detected at 22:00:34 UT on 2022 July 3. Its phase was 65 per cent with a phase (or scattering) angle of 72.4°. The L5 KDC was observed at 23:02:52 UT on 2021 October 31 at 65 per cent phase with 73.1° phase (scattering) angle. In the photographs shown in Fig. 1, we detect no discernible structure in scattered light, which suggests that the KDCs are very faint in scattered light. On the other hand, in the pattern of the degree of linear polarization p, a few diffuse elongated conglomerata of black pixels with 5 per cent $\leq p \leq$ 20 per cent are clearly visible at and around the L4 and L5 points. The same conglomerata of red pixels with $81^\circ \leq |\alpha| \leq 90^\circ$ are also seen in the patterns of the angle of polarization α. In the red (650 nm) and blue (450 nm) spectral ranges, the p- and α-patterns were practically the same as those measured in the green part of the spectrum (Fig. 1).

It is a very important feature that all local directions of polarization (short white bars in the α-patterns) are almost exactly orthogonal to the plane of scattering (yellow line). The reason for small deviations from this orthogonal direction is mainly the perspectivic effect due to the relatively wide (7.5° × 5°) field of view of our telescope. This expected orthogonal characteristic is typical for all scattering phenomena and proves that around the L4 and L5 points many light-scattering centres exist. These scatterers cannot be anything else but dust particles. Thus, Figs 1(C) and 1(D) present the first polarimetric evidence for the existence of the KDC around the L4 Lagrange point of the Earth-Moon system, while Figs 1(G) and 1(H) display the third polarimetric evidence for the existence of the L5 KDC which has already been polarimetrically detected two times on 2017 August 17 and 18 (Slíz-Balogh et al. 2019).

Hence, both the L4 and L5 KDCs have a striped structure with a few (4 for the L4 KDC in Figs 1(C), 1(D), and 2 for the L5 KDC in Figs 1(G), 1(H)) elongated dust conglomerata, and this structure is very similar to that of the L5 KDC obtained with three-dimensional computer simulations (Slíz-Balogh et al. 2018). Note that Kordylewski (1961) has observed two bright patches around the L5 Lagrange point. The only relevant difference between the observed L4 and L5 KDCs is that the angles β between the long axes of the elongated dust conglomerata and the scattering plane are different: $-20^\circ < \beta_{L4} < -10^\circ$ and $+35^\circ < \beta_{L5} < +45^\circ$ measured clockwise from the scattering plane. Comparing the simulated particle density (Slíz-Balogh et al. 2018) and the polarimetrically measured polarization patterns of the L4 and L5 KDCs (Fig. 1), a remarkable similarity can be seen: in these patterns a multipartite structure occurs with several elongated blobs, showing that the KDCs are a heterogenous particle conglomeratum.

Fig. 2 displays the distributions (normalized frequencies) of the degree of linear polarization p and angle of polarization α of the L4 and L5 KDCs measured at 22:00:34 UT on 2022 July 3 and at 23:02:52 UT on 2021 October 31. The most frequent p-values are 3.5 and 4 per cent for the L4 and L5 KDC (Figs 2(A) and 2(B)), and the maximum value is about 10 per cent. The peaks of the α distributions are at an angular distance of 90° from the direction of the scattering plane for both KDCs (Figs 2(C) and (D)), which refers evidently to scattering of sunlight on the KDC's particles.

Fig. 3 shows the photograph, the p- and α-patterns and the distributions of p and α measured at 20:14:51 UT on 2022 July 24 when the L4 point was not within the same celestial window as that of Fig. 1(A–D). The most frequent p-values are smaller than 1 per cent (Fig. 3(E)), and the maximum value is smaller than 4 per cent. The peak of the α distribution is at an angular distance of 73° from the direction of the scattering plane (Fig. 3(F)). The scatters of both p and α distributions are very small ($< \pm 0.5$ per cent, $< \pm 2^\circ$). The photograph as well as the p- and α-patterns are structureless: apart from the bright celestial bodies, the radiance is homogeneous dark, the degree of linear polarization is very low ($p < 4$ per cent) and the direction of polarization is not perpendicular to the scattering plane. These values mean that in this celestial window and in this point of time the polarization signal was practically unpolarized and homogeneous. These characteristics prove the absence of the L4 KDC in this celestial window and refer to the lack of particles which could scatter and polarize the sunlight.

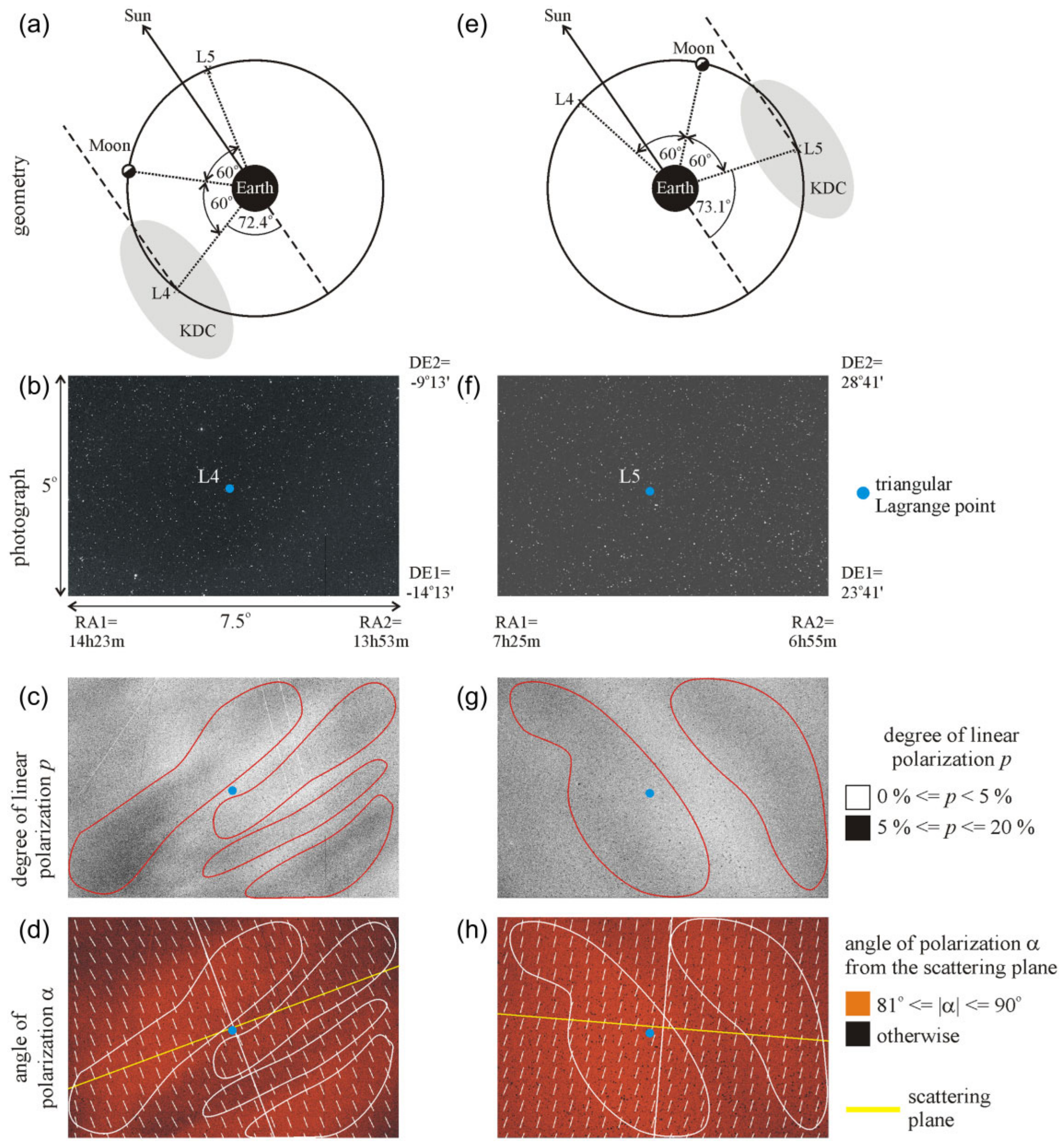

Figure 1. Imaging polarimetry of both KDCs. Geometry (position of the Moon, the L4 and L5 Lagrange points, and the KDC in the plane of the Moon's orbit), photograph, patterns of the degree p and angle α (measured from the scattering plane shown by a yellow line in the α-patterns) of linear polarization of the sky around the L4 (A–D) and L5 (E–H) points of the Earth–Moon system measured by imaging polarimetry in the green (550 nm) spectral range. (A–D) 22:00:34 UT, 2022 July 3, dust cloud phase: 65 per cent, phase angle: 72.4°, picture centre: RA = $14^{h}11^{m}3\overset{s}{.}89$, DE = $-11°39'10\overset{''}{.}65$. (E–H) 23:02:52 UT, 2021 October 31, dust cloud phase: 65 per cent, phase angle: 73.1°, RA = $7^{h}9^{m}26\overset{s}{.}57$, DE = $26°9'40\overset{''}{.}3$. Positions of the L4 and L5 points are shown by blue dots. 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 centre of the picture, respectively. The countours of the most prominent patches of the KDCs are highlighted in both the p-pattern (conglomerata of black pixels with 5 per cent $\leq p \leq$ 20 per cent) and the α-pattern (red pixels with $81° \leq |\alpha| \leq 90°$). The p- and α-patterns are very similar in the red (650 nm) and blue (450 nm) spectral ranges. Apart from the orthogonal white and yellow straight lines, the straight tilted lines in the p- and α-patterns are traces of satellites.

4 DISCUSSION

In this work, we show for the first time the polarimetric observation of the KDC around the stable triangular Lagrange point L4 of the Earth–Moon system. The elusive dust structures around the two triangular points of the Earth and Moon are still not fully accepted in the scientific community, and we are providing here support for the KDC's existence in both the L4 and L5 points. We present one successful detection of the L4 KDC performed on 2022 July 3. While the scattered light itself is too faint for a photometric telescope, we used to show a positive KDC detection, polarization images displaying structures with polarization angles excluding any terrestrial origin and pointing towards extra-terrestrial sources of scattered polarization. We also provide a positive detection of extended structures close to the L5 point of the Earth–Moon system from 2021 October 31.

According to the computer simulations by Slíz-Balogh et al. (2018), the KDC around the triangular Lagrange points L4 and L5 of the Earth–Moon system have a dynamical structure with inhomogeneous, temporally changing particle density composed of

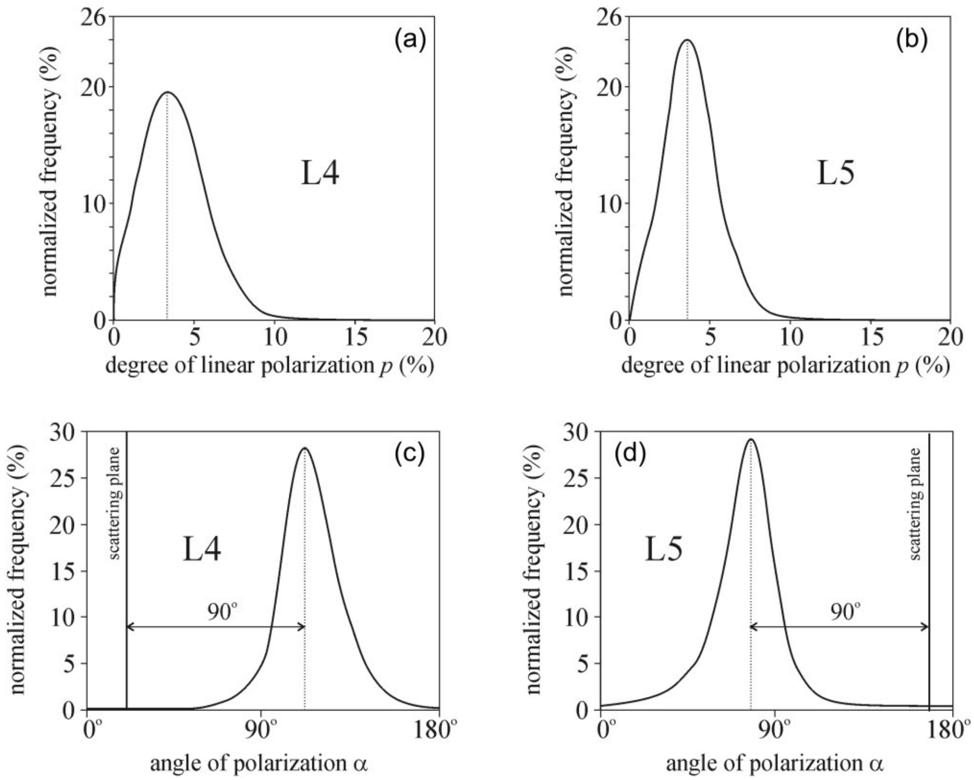

Figure 2. Normalized frequencies (per cent = number of pixels with a given p- or α-value divided by the total number of pixels of the pattern) of the degree of linear polarization p (A, B) and angle of polarization α (C, D) measured around the L4 (A, C) and L5 (B, D) Lagrange points of the Earth–Moon system. (A, C) 22:00:34 UT, 2022 July 3, dust cloud phase: 65 per cent, phase angle: 72.4°. (B, D) 23:02:52 UT, 2021 October 31, dust cloud phase: 65 per cent, phase angle: 73.1°.

several conglomerata of interplanetary dust. Since these dust clouds are illuminated by direct sunlight, the faint light scattered from the dust particles can be photographed from the Earth surface with enough radiance-sensitive detectors. Such a pioneer photographical documentation has been first performed by Kordylewski (1961). According to the few other successful trials (Vanysek 1969; Roach 1975; Winiarski 1989), the KDC can photometrically or visually be detected only from small phase/scattering angles (determined by the Sun, the L4/L5 point and the observer), i.e. at or near 'full dust moon', although these photos, just like Kordylewski's photographs were too faint for reproduction in newspapers or scientific journals. In this case the degree of polarization p of dust-scattered sunlight is minimal, practically zero. Since at phase/scattering angles near to 90° the p of dust-scattered sunlight is maximal, it is the highest chance to detect polarimetrically the KDC under this condition. Using imaging polarimetry, we successfully detected the polarization signature of both KDCs around the L4 and L5 points of the Earth–Moon system with relatively high (72.4° and 73.1°) phase/scattering angles (Fig. 1).

In case of the L5 KDC observed by us on 2021 October 31, the most frequent p-value is $p_{\mathrm{peak,\,L5}} = 4$ per cent (Fig. 2(B)), while in case of the L5 KDC observed by Slíz-Balogh et al. (2019) on 2017 August 18 $p_{\mathrm{peak,\,L5}} = 7$ per cent. Compared to the p_{peak}-value (7 per cent) of the L5 KDC detected by Slíz-Balogh et al. (2019), the smaller p_{peak}-value (4 per cent) of the L5 KDC observed by us in 2021 can be explaned by the fact that the closer the angle of scattering is to 90°, the higher the p is of scattered light. On 2021 October 31, the scattering angle of 73.1° was smaller than that of 87.3° on 2017 August 18.

Dust-scattered sunlight becomes partially linearly polarized with direction of polarization perpendicular to the scattering plane determined by the Sun, the ground-based observer and the dust region observed (Können 1985; Coulson 1988; Collett 1994). We found exactly this polarization characteristics in the patterns of the angle of polarization of the L4 and L5 KDCs (Figs 1, 2(C) and 2(D)). This is the strongest proof that we observed sunlit light-scattering dust clouds outside the Earth's atmosphere, rather than a terrestrial phenomenon. A further fact supporting that we observed both KDCs is that in the measured p- and α-patterns 2–4 dust conglomerata occur, as earlier simulations suggested (Slíz-Balogh et al. 2018).

With control measurements, Slíz-Balogh et al. (2019) have excluded the possibility that with the used polarization-sensitive telescope they detected an artificial optical phenomenon, rather than the L5 KDC: They showed that the detected polarization signals did not originate from an unwanted reflected/scattered/diffracted light within the telescope or from the terrestrial optical environment. This possibility was excluded by a control measurement when the L5 point was outside the celestial window studied, and thus the typical, theoretically forecasted characteristics of the L5 KDC were not registered. Slíz-Balogh et al. (2019) have also demonstrated that the detected L5 KDC was neither a thin cirrus cloud, nor a condense stripe of an airplane, because the polarization characteristics of these celestial objects are quite different from those expected for the KDC. Due to these earlier control measurements for the first and second polarimetric observation of the L5 KDC on 2017 August 17 and 18, we thought unnecessary to repeat such a control for the L5 KDC detected by us for the third time on 2021 October 31. On the other hand, we performed a control measurement in the same

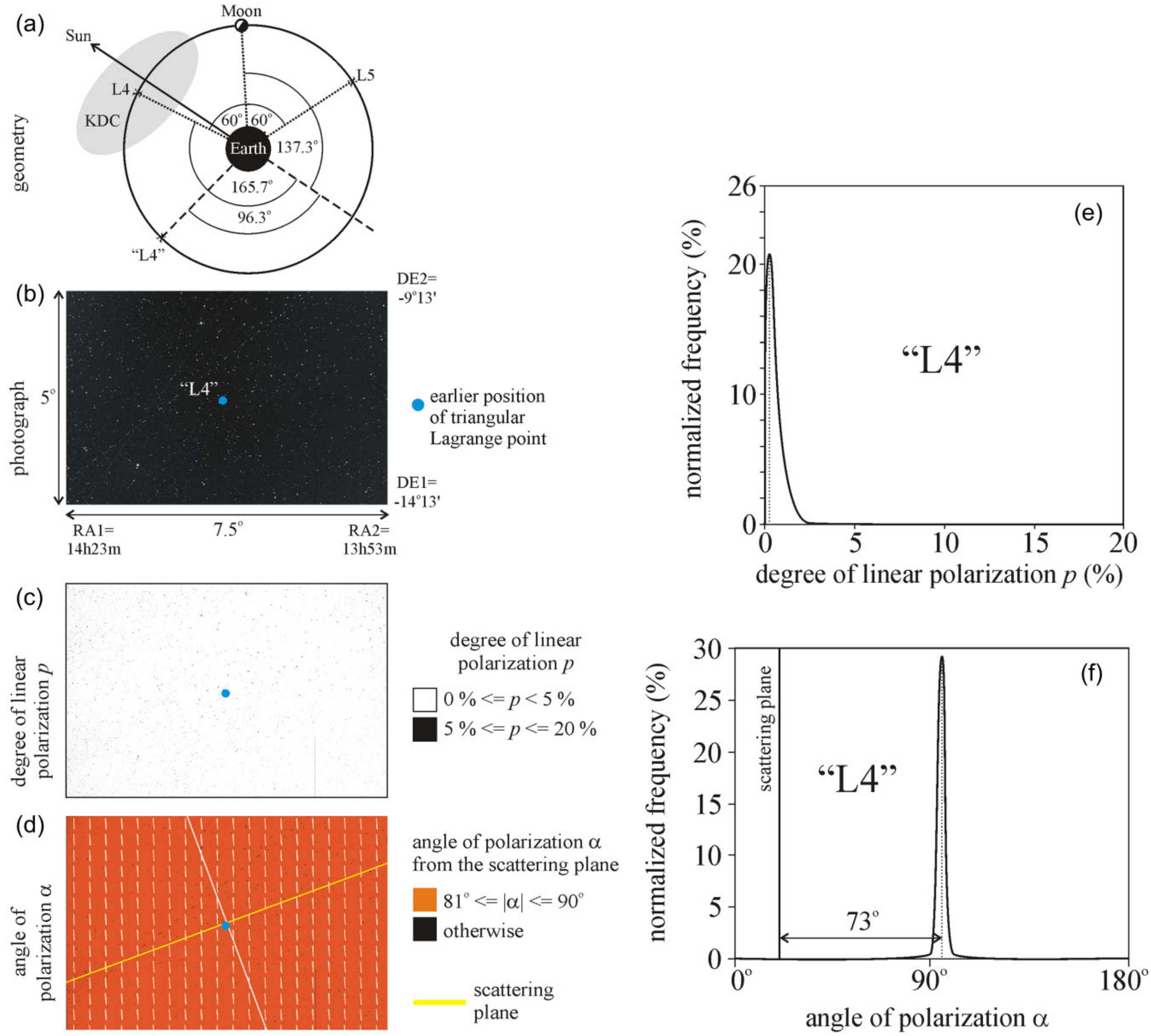

Figure 3. (A–D) As Fig. 1(A–D) for the measurement performed at 20:14:51 UT on 24 July 2022 (phase angle: 96.3°, picture centre: RA = $14^{h}11^{m}3^{s}.89$, DE = $-11°39'10''.65$) when the L4 point was not within this celestial window, therefore the blue dot 'L4' represents the earlier L4 position at 22:00:34 UT on 2022 July 3 (see Fig. 1(B–D)). (E, F) As Fig. 2(A, C) measured at 20:14:51 UT on 2022 July 24 when the L4 point was not within the same celestial window as that of Fig. 1(A–D).

celestial window where the L4 KDC was detected on 2022 July 3 (Fig. 3). In these practically unpolarized and quite homogeneous control polarization patterns no any specific structure occurred. Most remarkably, the structural and polarization characteristics of the L4 KDC detected on 2022 July 3 are very similar to those of the L5 KDC observed on 2017 August 17 and 18 and 2021 October 31 (Figs 1 and 2).

The source of KDCs is the photometrically hardly detectable interplanetary and interstellar dust originating from comets and colliding asteroids. It is mainly observed in the infrared range. Apart from the KDCs, other researchers reported about the following extraterrestrial sources of scattered light:

(i) Based on computer modelling and IRAS observations, Nesvorny et al. (2006) found that the sources of two dust bands observed by IRAS are the Karin and Veritas asteroid families. The former and latter originates from a disrupted asteroid with a diameter of ~30 and >100 km, respectively. However, the sources of the zodiacal light are mainly comets, because asteroidal sources are too small to produce the observed infrared flux.

(ii) Espy, Dermott & Kehoe (2009) revealed the existence of an additional Solar System dust band at 17° inclination. To determine the parent body of this band, they created a dynamical model of the formation of this dust band.

(iii) Based on observations by the *Spitzer Space Telescope*, Reach (2010) measured the azimuthal structure of the Earth's resonant dust ring. This ring is not steady and is azimuthally asymmetric: there is a relative paucity of particles within 0.1 au of the Earth.

(iv) The interstellar dust, albeit much rarer than the interplanetary dust, can be detected using data from the Sloan Digital Sky Survey (SDSS). Roman, Trujillo & Montes (2020) carried out a comprehensive study of the Galactic cirri within the Stripe82 region with the use of SDSS. They analysed a total area of 26.5 deg^2 and determined the optical colours of the interstellar dust.

Our control measurement (Fig. 3) excludes the possibility that with our polarimetric telescope we observed these extraterrestrial optical phenomena. If the L4 KDC observed by us polarimetrically (Figs 1(C) and 1(D)) were part of the scattering of sunlight by the above-mentioned extraterrestrial background dust sources, then the p- and α-patterns of Fig. 3 without the L4 KDC should also have some heterogeneous (e.g. patched or banded) polarization characteristics instead of the obtained homogeneously unpolarized patterns.

On the basis of the above, we conclude that for the first time we observed polarimetrically the KDC around the stable triangular Lagrange point L4 of the Earth–Moon system, and we detected the L5 KDC for the third time. By these we confirmed the existence of both KDCs of the Earth and Moon observed first by Kordylewski (1961) both visually and photographically.

Continuing our astropolarimetric study after the two polarization observations of the L5 KDC on 2017 August 17 and 18 (Slíz-Balogh et al. 2019), we had either no time for an observation, or had never an appropriate astroclimate (i.e. ideally aerosolfree atmosphere) for imaging polarimetry of the KDCs. In Hungary, an ideal astroclimate for this task exists yearly only for a few days. Hence, waiting for such aerosolfree nights and enough time for an observation, in the last two years, we could detect polarimetrically one of the two KDCs only on 2021 October 31 and 2022 July 3. We have only one polarimetric control observation on 2022 July 24 (Fig. 3) when the L4 Lagrange point was not within the celestial window in which the L4 KDC was detected on 2022 July 3. Note that our successful observations were performed with imaging polarimetry, while all earlier research groups attempted to observe the KDCs either with photometry, or the naked eye. Our KDC observations detected the unambiguous polarization signal of dust-scattered sunlight characterized by directions of polarization perpendicular to the scattering plane. This typical polarization feature could not have been formed by any noise-based artefact.

In order to increase considerably the number of polarimetric observations of the KDCs, we are designing and building a portable wide-field-of-view telescope equipped with a rotating-analyser imaging polarimeter, with which we shall study the characteristics and dynamics of the L4 and L5 KDCs in regions with ideal astroclimate (planned in the Isabis Astro Lodge of the Namibian desert). With this portable imaging-polarimetric telescope we shall also try to observe the above-mentioned extraterrestrial sources of scattered polarized light.

ACKNOWLEDGEMENTS

We are grateful to the reviewer (Petr Pokorny) for his valuable and constructive comments about an earlier version of our manuscript. This work was supported by the Hungarian Office of Supported Research Groups, Eötvös Loránd Research Network (grant number: ELKH-ELTE-0116607 Astropolarimetry). Substantial contributions to conception and design: JSB, AM, PS, AB, and GH. Performing experiments and data acquisition: JSB. Data analysis and interpretation: JSB, AB, and GH. Drafting the article or revising it critically for important intellectual content: JSB and GH.

DATA AVAILABILITY STATEMENT

The data underlying this article are available in the article which has no electronic supplementary material.

COMPETING INTERESTS

The authors declare no competing interests and have no conflict of interest.

REFERENCES

Bruman J. R., 1969, Icarus, 10, 197
Collett E., 1994, Polarized Light: Fundamentals and Applications, Marcel Dekker, New York
Coulson K. L., 1988, Polarization and Intensity of Light in the Atmosphere. Deepak Publishing, Hampton, VA
Espy A. J., Dermott S. F., Kehoe T. J. J., 2009, BAAS, 41, 906
Igenbergs E. et al., 2012, in Levasseur-Regourd A. C., Hasegawa H., eds, Origin and Evolution of Interplanetary Dust. Kluwer Academic Publishers, New York, p. 45
Kordylewski K., 1961, Acta Astron., 11, 165
Können G. P., 1985, Polarized Light in Nature, Cambridge Univ. Press, Cambridge
Murray C. D., Dermott S. F., 1999, Solar System Dynamics, Cambridge Univ. Press, Cambridge
Nesvorny D., Vokrouhlicky D., Bottke W. F., Sykes M., 2006, Icarus, 181, 107
Rajnai R., Nagy I., Érdi B., 2014, MNRAS, 443, 1988
Reach W. T., 2010, Icarus, 209, 848
Roach J., 1975, Planet. Space Sci., 23, 173
Roman J., Trujillo I., Montes M., 2020, A&A, 644, A42
Roosen R. G., 1966, Sky Telesc., 32, 139
Roosen R. G., 1968, Icarus, 9, 429
Roosen R. G., Harrington R. S., Jeffreys W. H., 1967, Phys. Today, 20, 9
Salnikova T., Stepanov S., Shuvalova A., 2018, Acta Astronaut., 150, 85
Simpson J. W., 1967, Phys. Today, 20, 39
Slíz J., Süli Á., Kovács T., 2015, Astron. Notes, 336, 23
Slíz J., Kovács T., Süli Á., 2017, Astron. Notes, 338, 536
Slíz-Balogh J., Barta A., Horváth G., 2018, MNRAS, 480, 5550
Slíz-Balogh J., Barta A., Horváth G., 2019, MNRAS, 482, 762
Slíz-Balogh J., Érdi B., Horváth D., Horváth G., 2022, Icarus, 374, 114814
Szebehely V., 1967, Theory of Orbits: The Restricted Problem of Three Bodies, Academic Press, New York
Valdes F., Freitas R. A., Jr., 1983, Icarus, 53, 453
Vanysek V., 1969, Nature, 221, 47
Wang P. et al., 2021, Space Sci. Tech., 2021, 6597921
Winiarski M., 1989, Earth Moon Planets 47, 193
Wolff C., Dunkelman L., Hanghney L. C., 1967, Science, 157, 427

This paper has been typeset from a Microsoft Word file prepared by the author.