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Bogdan Wszołek i Agnieszka Kuźmicz

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Słowa wstępne / Forewords

W dziesiątą rocznicę istnienia Stowarzyszenia Astronomia Nova (AN) postanowiliśmy powołać do istnienia Annales – oficjalne pismo AN, na którego łamach astronomowie oraz przedstawiciele nauk pokrewnych astronomii mogliby zamieszczać raporty z dokonań na polu nauki, wyrażać opinie w sprawach naukowych i okołonaukowych, przybliżać epizody z historii nauki, oddziaływać dydaktycznie na osoby zainteresowane naukami przyrodniczymi.

Annales Astronomiae Novae (AAN) z założenia mają być pismem niezależnym politycznie i niekoniecznie podporządkowującym się stereotypom i trendom mody w zakresie upowszechniania wiedzy naukowej. Od autorów przyczynków oczekuje się intencji szczerego podzielenia się wiedzą, dokonaniami i przemyśleniami z czytelnikami, nie zaś czysto interesownej (obliczonej na punkty, granty etc.) aktywności. Autorzy przyczynków, członkowie Komitetu Naukowego i redaktorzy Annales najpewniej będą działać bezinteresownie i bez żadnej gratyfikacji finansowej. Przeciwnie, niejednokrotnie zainwestują dodatkowo swoje środki finansowe na druk pisma. Treści przesyłane do AAN powinny przypominać coś, co się mówi osobiście przyjaciołom prawdziwej nauki.

Ten years have passed since the establishment in 2009 the Astronomia Nova Association (AN). Recently, we decided to set up Annales – the official AN magazine (AAN). It is intended to be an independent, high-level opinion-forming scientific journal. In its pages, astronomers and representatives of astronomy-related sciences would publish reports on achievements in the field of science, express opinions on purely scientific and scientific-related matters, present interesting episodes concerning the history of science as well as exert an appropriate influence on people interested in natural sciences.

Annales Astronomiae Novae is intended to be a politically independent magazine and not necessarily subordinate to stereotypes and various trends of scientific fashion in the process of dissemination of scientific knowledge. The authors of the publications are expected to honestly share their knowledge, original scientific achievements and thoughts with the readers. They should avoid activity focused only on accumulating points or obtaining lucrative grants etc. Authors, members of the Scientific Committee, and editors of Annales will receive no financial rewards. Indeed, we hope they will provide some financial support toward printing and toward publishing the magazine. Content submitted to AAN should be the sorts of things you would say in person to the friends of real science.

Bogdan Wszołek

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New journal Annales Astronomiae Novae is planed to be a multi-directional publication, which will be directed to new research papers, reviews, as well as to the popular papers. It is aimed to interchange knowledge between scientists of different directions related to astronomy and cosmonautics. The scientific comittee (board of Editors) is international and includes astronomers from different Universities and countries. Scientific papers will be referred in the Astrophysics Data System (ADS) and will contribute to the world-wide astronomical community.

May I wish all the best to Dr. Bogdan Wszołek, the Editor-in-Chief, who makes a great impact to the Public Outreach in Poland and other countries, as well as to the authors, editors and readers of the journal Annales Astronomiae Novae.

Ivan Leonidovich Andronov

*

Annales Astronomiae Novae wyrasta z dziesięcioletniej historii Stowarzyszenia Astronomia Nova, która dowiodła, że środowisku astronomów potrzebne jest forum wymiany myśli, doświadczeń oraz wspomnień poza głównym nurtem publikowania w indeksowanych wysoce specjalistycznych czasopismach. Intencją AAN jest stworzenie takiej platformy komunikacji pozwalającej na prezentowanie szerokiego spektrum prac: od oryginalnych wyników naukowych, przybliżania spraw “dobrze znanych” (lecz jedynie znawcom tematu) aż po unikalne opracowania historyczne. A wszystko to w dbałości o dotrzymanie należytych standardów naukowych.

Annales Astronomiae Novae stems from a decade of history of the Astronomia Nova Association. This history proved that astronomical community needs a dedicated forum of exchanging thoughts, experience and memories beyond the mainstream of publishing in the indexed highly specialized journals. The intention of the AAN is to create such a platform of communication allowing to present a wide spectrum of papers: from original scientfic results, contributions giving a sense of “the well known” (but only to those who know well) up to unique historical studies. All of this with the utmost care about proper scientific standards.

Marek Biesiada

*

Prawdziwa pasja jest cenna i rzadka, a na świecie, także w nauce, promowany jest przede wszystkim specyficzny profesjonalizm: duże pieniądze, duże projekty, wykonywanie wskazanych zadań. Jednoautorskie publikacje szybko zanikają w wiodących czasopismach astronomicznych, takich jak Astrophysical Journal. Tak musi być, bo skoordynowana praca setek czy tysięcy naukowców wymaga takiego podejścia. Ale ta profesjonalna nauka ma też swoje cienie, ludzie często tracą radość bycia twórczymi, pieniądze idą za trendami, a trendy nie zawsze mają swoje uzasadnienie. Czasami trzeba zawrócić z utartej ścieżki i zacząć wszystko od nowa. Dlatego tak ważne jest, aby zawsze byli ludzie gotowi do refleksji, do świeżego spojrzenia, gotowi robić coś innego. Ci ludzie to ludzie, którzy robią to, co robią właśnie dla przyjemności, z pasji. Jestem pewna, że AAN, podobnie jak poprzednio Częstochowski Kalendarz Astronomiczny, zgromadzi wokół siebie właśnie takich pasjonatów.

True passion is precious and infrequent, and in the contemporary world, also in science, another, more professional approach is promoted, connected with large projects, large money involved, and performance according to the plan. Single-author papers systematically disappear from the leading astronomical journals, like The Astrophysical Journal. It must be so, since coordinated work of hundreds or even thousands of astronomers requires such approach. But this approach has also the negative aspects, people are loosing a chance to be creative, money follow the established trends, and those trends are not always justified. Sometimes it is necessary to make a few steps back and start again. For that there is a need for people happy to provide a fresh and new point of view, ready to do something different. Such people are among those passionates who do science for pleasure. I am sure that AAN, as the Częstochowa Astronomical Calendar before, will gather such enthusiasts.

Bożena Czerny

*

W czasach powszechnego i łatwego dostępu do informacji zalewa nas ogrom doniesień, których wiarygodności – z braku czasu, lenistwa czy niewiedzy – nie jesteśmy w stanie sprawdzić. Otacza nas i zalewa błyskotliwa, ale niestety szkodliwa pseudonauka. Choroba ta dosięga również astronomię. Naszą obroną powinno być propagowanie nauki w sposób ciekawy, zrozumiały, nowoczesny, ale nade wszystko rzetelny i prawdziwy. W trosce o wysoką jakość prezentowanych na łamach AAN tekstów, wszystkie one będą poddawane recenzji niezależnych ekspertów.

In these times of universal and easy access to information we are incessantly bombarded with reports which, through lack of time, indolence or inadequate knowledge, we are virtually not able to verify. There is a great amount of apparently brilliant, while definitely harmful, pseudoscience around. This condition also affects astronomy. As an effective remedy, we should promote science in a way that is attractive, comprehensive and up-to-date, but in the first place reliable and truthful. In order to ensure a high level of quality, the texts to appear in AAN will all be reviewed by independent experts.

Marek Jamrozy

*

Po co nowe pismo na i tak już zatłoczonym rynku czasopism astronomicznych? Otóż AAN nie są pismem tak naprawdę nowym – wyrastają z tradycji i doświadczeń Częstochowskiego Kalendarza Astronomicznego, którego piętnastoletnia historia pokazała, że tak czytelnicy, jak i autorzy potrzebują forum, które łączy różne konwencje. Również i AAN zamieszczać będą obok artykułów prezentujących oryginalne osiągnięcia naukowe, także i opracowania historyczne zawierające – jak to bywało w przeszłości – unikalne nierzadko materiały, a dodatkowo kroniki bieżących wydarzeń i komentarze. Redakcja liczy na to, że połączenie w jednym tomie tych wszystkich elementów przyczyni się do integracji szeroko pojętego środowiska astronomicznego, ale także do promowania prawdziwej jakości w uprawianiu astronomii, o którą trudno bez szerokiej perspektywy – historycznej, geograficznej i, nie da się ukryć, także i międzyludzkiej.

Why a new journal in the already crowded market of astronomy science journals? AAN are not really a new thing – they stem from the tradition and experience of the Częstochowa Astronomical Calendar, whose ten-year history has shown that both readers and authors need a forum that combines different conventions. Following and modernizing this tradition, AAN will also publish original scientific articles, as well as historical studies containing – as it used to be in the past – unique materials, and chronicles of current events and commentaries. The editors believe that the combination of all these elements in one volume will contribute to the integration of the broadly understood astronomical community, and also to the promotion of true quality in astronomy, which in fact requires a broad perspective – historical, geographical and, last not least, interpersonal.

Agnieszka Pollo

*

A hearty welcome to Annales Astronomiae Novae! We astronomers and friends definitely need more venues in which we can discuss our science and our society in serious, but not solemn, ways, the more so since some journals (like Quarterly Journal ofthe Royal Astronomical Society) which permitted this have ceased to exist, and others (like Publications of the Astronomical Society of the Pacific) have become more focussed on regular astronomical research papers. I am very pleased indeed to have two of my own efforts, one on history of astronomy and one on a sociological topic, appear in this first volume!

Virginia Trimble

Spis treści

Imaging polarimetry of the Kordylewski Dust Cloud in the Lagrange point L5 of the Earth and Moon

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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 L5. 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 L5. 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 (L1, L2, L3) and in 1772 Lagrange found two triangular points (L4, L5) in the gravitational field of two bodies moving under the sole influence of mutual gravitational forces (e.g. [21]). In the three-body problem of celestial mechanics the L4 and L5 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 $Q^* = 0.0385$ (e.g. [13]). 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 L4 and L5 points of the Sun-Jupiter system ([18], [17]). Minor planets have also been found around the triangular Lagrange points of the Sun-Earth (e.g. [6]), Sun-Mars (e.g. [2]) and Sun-Neptune systems (e.g. [19]).

What about the vicinities of the Lagrange points L4 and L5 of the Earth and Moon? Since the mass ratio $Q = m_{Moon}/(m_{Earth} + m_{Moon}) = 0.012195$ of the Moon and Earth is smaller than $Q^* = 0.0385$, the L4 and L5 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.

In 1961 Kordylewski found two bright patches near the L5 point, which may refer to an accumulation of dust particles ([10]). Since that time this hypothetic formation is called the Kordylewski dust cloud (KDC). 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 conglomeratum of particles not escaped from the system sooner than 3650 days around L5.

Using ground-born imaging polarimetry, we presented a new observational evidence for the existence of the KDC around the L5 point of the Earth–Moon system. Excluding artefacts induced by the telescope, cirrus clouds, or condensation trails of airplanes, the only explanation remained the polarized scattering of sunlight on the particles collected around the L5 point. By our polarimetric detection of the KDC we think it is appropriate to reconsider the pioneering photometric observation of Kordylewski. Our polarimetric evidence is supported by the results of simulation of dust cloud formation in the L5 point of the Earth–Moon system.

Results

Theoretically, there are extended small-concentration particle clouds around the L4 and L5 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 ([12]), Kordylewski ([10]) was the first to photograph two faint patches near the L5 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 L5 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 skyglow ([14]).

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 antisolar point, the intensity of the zodiacal light is relatively enhanced, because each dust particle is seen in full phase. This phenomenon is the gegenschein (counterglow). So, it seems also the most convenient to photograph the KDC when it is near the antisolar 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 ([15], [16]) found no evidence to the existence of KDCs near the L4 and L5 points. He suggested that if the KDCs exist at all, they are not associated with the Earth-Moon libration points. Wolff et al. ([25]) did not find excess light in excess of 5 % of the light of the neighbouring night sky near the Lagrange points L4 and L5 of the Earth-Moon system, even though they photographed under astronomically favorable circumstances from an aircraft. However, Vanysek ([23]) 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 L4 and L5 points at large phase angles. Note that in the paper of [23] the phase angle of the antisolar point was 180°. Vanysek 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 L4 and L5 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 ([10]; [15], [16]; [25]; [23]) also hint at the possible transient feature of the KDC.

However, at a lunar eclipse the KDC could not be observed at all ([1]). A photographic search ([22]) did not find any objects at the Earth-Moon Lagrange points L4 and L5. The limiting magnitude for the detection of libration objects near L4 and L5 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 L4 and L5 points of the Earth and Moon system, but did not find an obvious increase in dust concentration compared to the surrounding space ([5]).

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 ([14]) concluded that these dust clouds do exist in the L4 and L5 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 ([24]) determined that the colours of the dust clouds near the L4 and L5 points differ from those of the counterglow (gegenschein), which means that the dust particles constituting them are also different.

According to our computer simulations, the KDC around the Lagrange point L5 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 ([10]). According to the other above-mentioned successful trials ([23]; [14]; [24]), the KDC can be visually detected only from small phase angles (determined by the observer, the Sun and the L4/L5 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 L5 point of the Earth and Moon (Figures 1 and 2). Due to the nearly 90° phase angle, the very faint light scattered by the KDC cannot be discerned in the colour photographs and the patterns of radiance *I* measured by us in the red, green and blue spectral ranges (Figure 2).

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 ([9]; [4]; [3]). We have indeed found this forecasted characteristic in the patterns of the angle of polarization measured with imaging polarimetry (Figure 2). 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.

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 1A, B and 2A, B). This is further convincing evidence that we registered the KDC with imaging polarimetry, rather than another phenomenon.

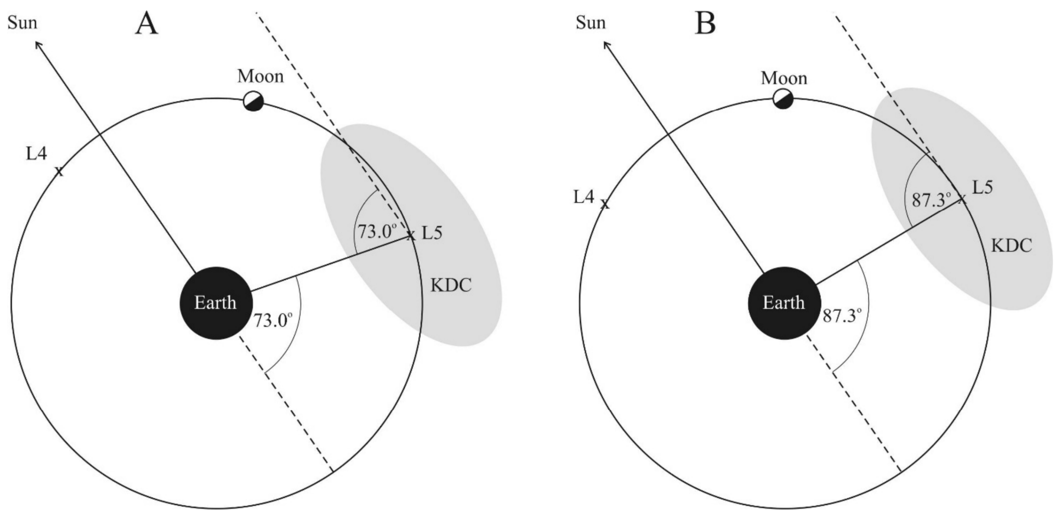

Figure 1. Positions of the Moon and the L5 Lagrange point of the Earth-Moon system in the plane of the Moon's orbit on 17 August 2017 at 23:29:67 UT with 73°.0 phase angle (A), and on 19 August 2017 at 01:14:15 UT with 87°.3 phase angle (B). Apart from the Earth and Moon, the relative dimensions are not to scale. The Sun's direction is indicated by an arrow. KDC: Kordylewski dust cloud.

All ground-based observing systems are confronted with the light pollution of manmade ground-born light sources. These artificial lights usually increase the degree of linear polarization of skylight due to atmospheric aerosols ([11]). Shkuratov et al. ([20]), Kocifaj ([7]) and Kocifaj et al. ([8]) 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. ([20]) demonstrated the so-called negative polarization induced by the multiple scattering of light on rough surfaces and aerosols. Kocifaj et al. ([8]) examined and compared the linear polarization of light scattered by homogeneous-sphere particles and Gaussian-core particles. Kocifaj ([7]) 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 L5 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 skyglow is perpendicular to the plane determined by the observer (polarimeter), the skyglowing 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 2) determined by the observer (polarimeter), the Sun and the L5 Lagrange point. Due to the minimal light pollution in our measurement site, a relevant contribution of skyglow to the measured polarization signature was out of question. A minimal skyglow could have appeared only near the horizon, but the field of view of our imaging polarimetric telescope was far from the horizon. Thus, skyglow effects were surely negligible.

Figure 3 shows the computer-simulated volume density distribution of particles of the KDC around the L5 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 L5 were measured.

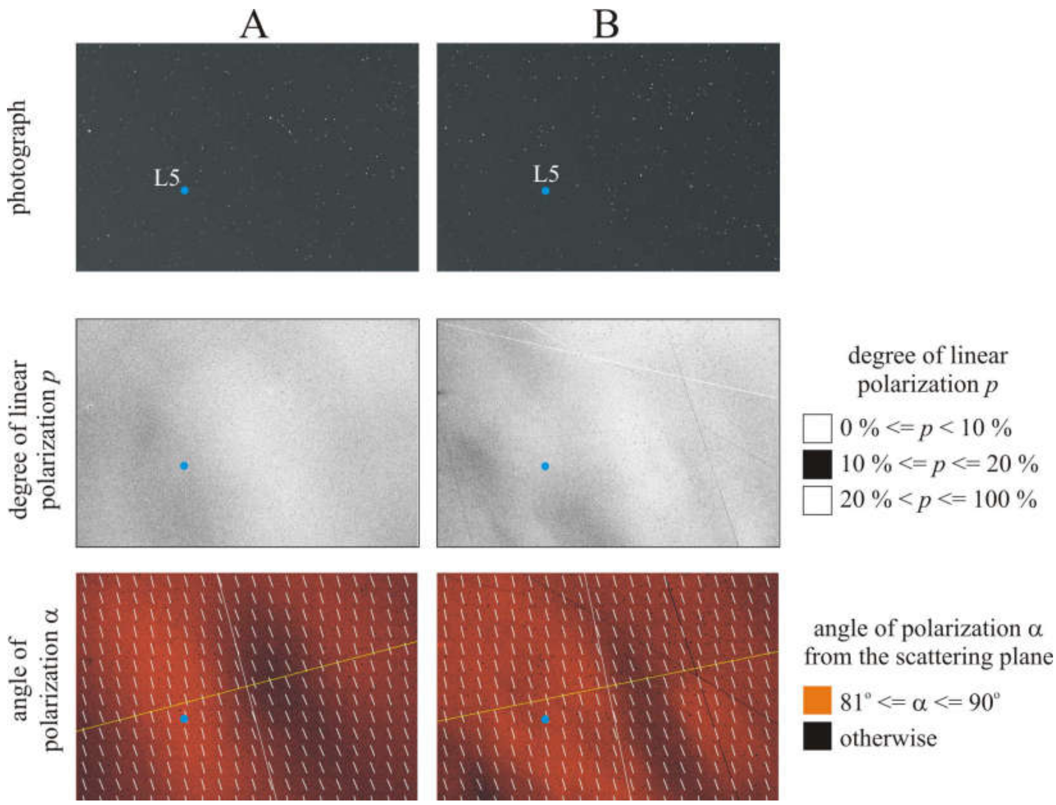

FIGURE 2. (A) Colour photograph, and patterns of radiance I, degree of linear polarization p and angle of polarization α (clockwise from the scattering plane) of the sky around the L5 Lagrange point of the Earth-Moon system measured by imaging polarimetry in the green (550 nm) spectral range at 23:29:67 UT on 17 August 2017 (picture center: RA = 2^h 12^m $28^s.2$, DE = $8°$ $3'$ $52''.6$) (A), and at 01:14:15 UT on 19 August 2017 (RA = 3^h 11^m $23^s.36$, DE = $12°$ $21'$ $15''.38$) (B). The position of the L5 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.

Figures 4 and 5 display the mosaic patterns of the degree of polarization p and angle of polarization α of the KDC around L5 measured in the green (550 nm) with imaging polarimetry on 19 August 2017. Comparing the simulated particle density and the measured polarization patterns, a remarkable similarity can be seen: in all three patterns a multipartite structure occurs with several elongated clusters, showing that the KDC is a heterogenous particle cluster. The polarization patterns of the different neighbouring windows cannot be exactly fitted, because the sequential polarimetric measurements happened in slightly

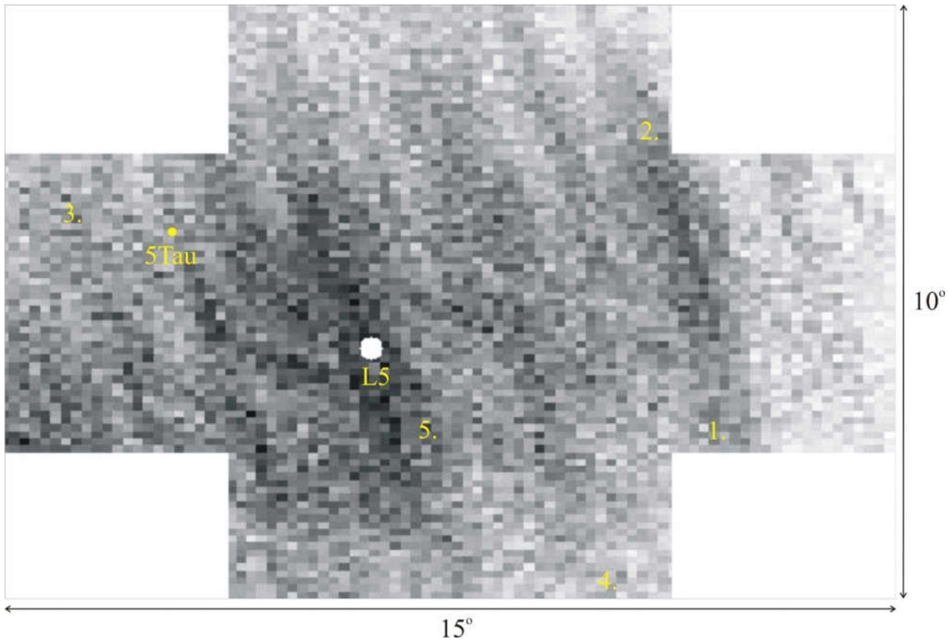

FIGURE 3. Computer-simulated volume density distribution of the particles of the KDC around the L5 point (white dot) of the Earth-Moon system. The darker the grey shade, the larger is the particle density. The numbered windows correspond to the fields of view of our imaging polarimetric telescope with which the polarization patterns of the sky around L5 were measured.

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 L5 of the Earth and Moon. By this we corroborated the existence of the KDC first observed photometrically by Kordylewski ([10]).

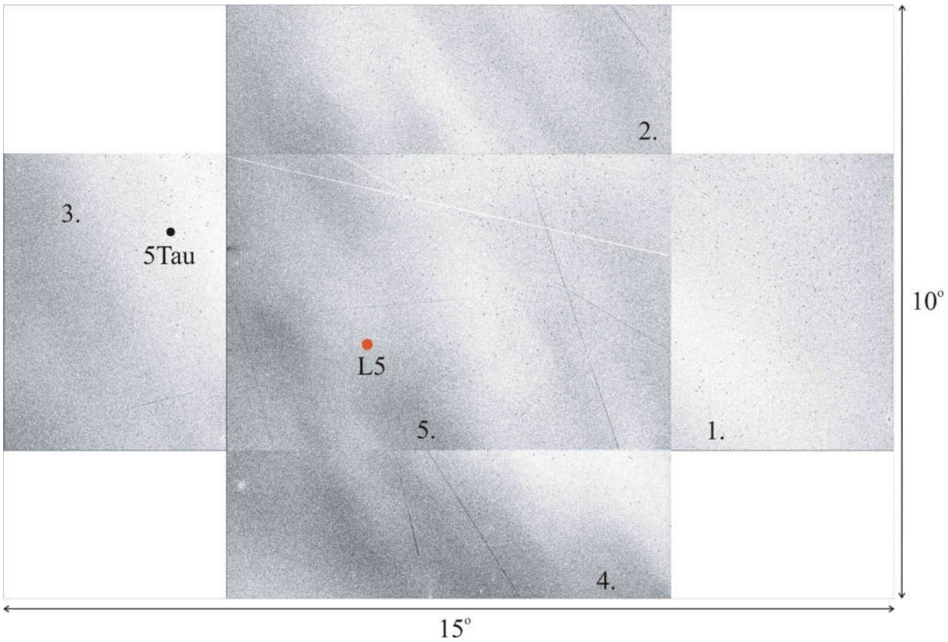

Figure 4. Mosaic pattern of the degree of linear polarization p of the KDC around the L5 point (red dot) measured on 19 August 2017 in the green (550 nm) with imaging polarimetry. The mean time (UT) of the patterns are: (1) 00:03:34, (2) 00:26:51, (3) 00:50:25, (4) 01:02:26, (5) 01:14:15.

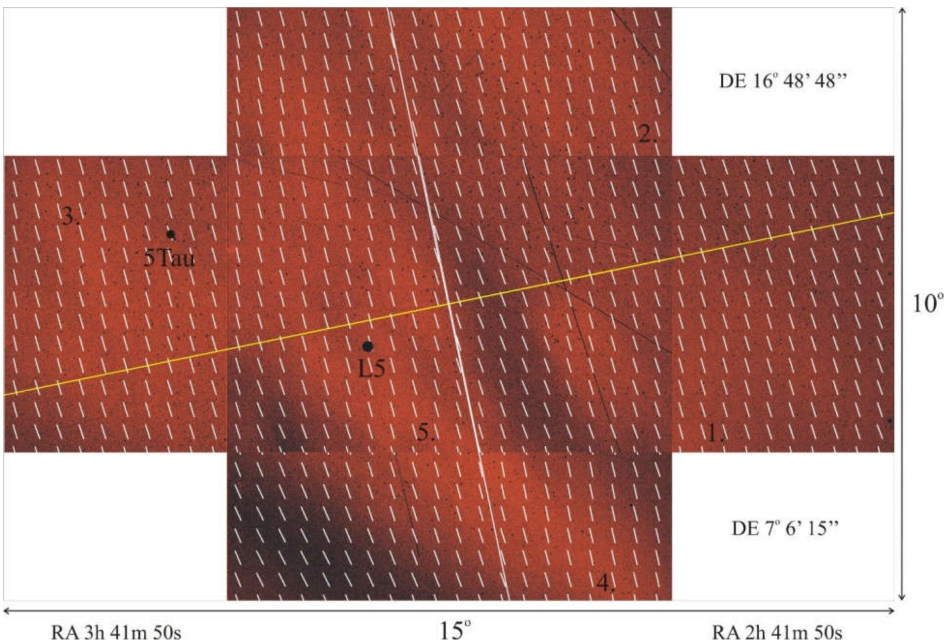

Figure 5. The angle of polarization α (clockwise from the scattering plane). The short white bars represent the local directions of polarization. The long yellow and white straight lines show the scattering plane and the perpendicular plane passing through the center of the picture, respectively.

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