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THE KORDYLEWSKY CLOUDS – AN EXAMPLE FOR A CRUISE PHASE OBSERVATION DURING THE LUNAR MISSION BW1

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ABSTRACT

The LUNAR MISSION BW1 is an academic small moon orbiting spacecraft which is currently under development by the Institute of Space Systems (IRS), Universitaet Stuttgart, Germany. This probe is part of the Stuttgart Small Satellite Program and will be designed, build and operated by the institute itself. The launch of the 1 m cube all electrical spacecraft of approx. 200 kg is planned for the end of the decade. Before arriving in lunar orbit to perform remote sensing experiments the satellite will spend between 12 and 24 months in cis-lunar space during its cruise phase. In addition to the regular propulsion operation phases there is room for science opportunities for doing remote sensing as well as in-situ measurement experiments.

Measurement of dust distribution or observations of Near Earth Objects (NEO) will be interesting topics. An opportunity not to be missed might be the study of the faint Kordylewsky Clouds at the Lagrangian points L4 and L5 of the Earth-Moon-System. Discovered in 1956 by Polish astronomer K. Kordylewsky it is an elusive feature hard to observe from Earth. It is assumed that the clouds consist of captured particles of small size. The clouds extend up to a diameter of approx. 10000 km.

This paper will discuss the possibilities of remote sensing observation of the Kordylewsky Clouds during the LUNAR MISSION BW1 cruise phase. Which observation methods will be employed, what kind of instruments might be feasible and how can such a campaign fit into the spacecraft operations? Scientific issues as composition, origin, movement and physical properties will be addressed. What can be gained by including a ground-based (amateur/outreach) observation campaign?

INTRODUCTION

In October 1956 the Polish astronomer Kazimierz Kordylewski (1903-1981) observed the Lunar Libration Clouds at the libration points L4 and L5 visually for the first time. In March and April of 1961 he took photographs of the clouds and published his findings in Acta Astronomica [1]. Since then a number of observers have obtained visual evidence ([2], [3]), photographic exposures ([4], [5]) or took measurements in wavelengths of 400-600 nm (OSO-6 observations [6]).

While in the past some scientists were able to observe the elusive Kordylewski clouds, other scientists have tried to find them but failed. More than 50 years after the first observation even the existence is still disputed by some researchers. Not surprisingly we know very little about the orbital and physical properties of the libration clouds. At the same time a number of future space missions plan to either pass through the L4/L5 libration points or have been chosen as a place to build Mars-bound spacecrafts. Before we attempt to use and occupy this region of space, it is necessary to positively proof or disproof the existence of the Lunar Libration Clouds and extensively study its properties.
The faint clouds are hard to detect from Earth and were never the primary target of a space based mission. A dedicated or carefully arranged space based mission with many observing opportunities will have the capability of finally answering the question about the existence and properties of the Kordylewski clouds. We propose a dedicated search and measurement campaign for the Kordylewski Clouds during the cruise phase of the Lunar Mission BW1 spacecraft.

CURRENT KNOWLEDGE

The crews of Gemini 12 [7], Apollo 14 [8] and Apollo 16 [9] took images of the libration point region but no final results were published. In 1991 the japanese Hiten (Muses-A) spacecraft passed through L4 and L5 but did not find an increase in dust particle ([10]). However there is a good chance that Hiten passed the libration points but missed the libration clouds which according to Simpson [4] orbit around L4/L5 in distances of several degrees.
Current knowledge based on scientific observations according to Roach [6] are:

- there is sufficient material at the-Earth-Moon libration points L4 and L5 to produce a solar counterglow of 20 S_{10} Vis brightness,
- these libration clouds are about 6 degrees in angular size as seen from the Earth,
- these libration clouds move around the libration point, over an elliptical zone with a semi-major axis of about 6 degrees along the ecliptic and a semi-minor axis of about 2 degrees perpendicular to the ecliptic,
- the libration clouds are closer to the Moon during the northern summer months, and away from the Moon during the northern winter months with respect to the Lagrangian point,

and according to Winiarski [5]:

- brightness is about half the brightness of the counterglow,
- color is much redder than the counterglow,
- this might indicate that the particles are of a different nature as in the counterglow.

SPACE-BASED OBSERVATIONS

A long duration cruise phase in cis-lunar space would provide excellent opportunity to study the Kordylewski Clouds over a long period of time and under a variety of different observing conditions. One suitable mission is the moon orbiter Lunar Mission BW1 of the Stuttgart Small Satellite Program accomplished by the Institute of Space Systems (IRS), Universitaet Stuttgart, Germany. With a launch not earlier than 2010 its flight to the Moon will last 12-24 months because of its low-thrust electric propulsion system and depending on the final launch configuration.
During the flight multiple measurements in various phase angles can be accomplished. Possible scientific objectives are:

- definition of orbital parameters,
- monitoring of halo movement over time,
- properties of the halo orbit,
- measurement of the variation of brightness with phase angle,
- implications for particle sizes and materials,
- upper and lower limits for particles, total mass and density
- spectral signatures,
- origin of the particles,
- link to the sodium tail reported to come from meteoroid impacts on the lunar surface [12]

LUNAR MISSION BW1 AND DUST INSTRUMENTS

The Lunar Mission BW1 is the fourth small satellite project of the “Stuttgart Small Satellite Program” initiated in 2002 at the Institute of Space Systems (IRS), Universitaet Stuttgart, Germany [15]. Three other different small satellite projects (earth observation/technology demonstration, electric propulsion systems/UV astronomy, reentry vehicle/GNC software) and ground segment facilities (integration laboratory, ground station, control centre) are currently under construction or development with participation of Diploma/Masters and Ph.D. students [16].

The small lunar orbiter equipped with solar-electric propulsion system which will provide approx. 1 kW power will perform remote sensing and technology demonstration experiments in a high-inclined low lunar orbit. Different potential technology demonstration topics (e.g. electric propulsion systems, target pointing observation, autonomous GNC, FPGA on-board computer, radio frequency and microwave communication and radio science, impact experiment) are identified as well as different potential scientific objectives for cis-lunar and lunar exploration (e.g. high resolution multi spectral, imaging, reflectance measurements, landing site and remnant observation, lunar impact flash detection).

Launched not earlier than 2010 as a piggyback payload with approx. 200 kg launch mass and a size of approx. 1 m cube into a Geo-synchronous Transfer Orbit (GTO) the satellite will be transferred to the Moon using two different electric propulsion systems (thermal arcjet and a cluster of instationary magneto plasma dynamical pulsed thrusters).

In addition to planned imaging systems (VIS/NIR, TIR and panoramic camera) as well as radio science experiments (in S/Ka band) a miniaturized piezo-based dust detector is under discussion.

In the field of dust research the Institute of Space Systems (IRS) is cooperating with the cosmic dust group of the Max-Planck-Institute for Nuclear Physics (MPI-K), Heidelberg, Germany to develop an advanced dust telescope. The dust telescope is a combination a dust trajectory sensor for identification and a large area mass analyzer to determine the elemental composition [13].

OBSERVATION SIMULATION

The contact times to the Lunar Libration Clouds and their equatorial coordinates at those times were calculated using the Satellite Tool Kit software developed by AGI (Analytical Graphics, Inc.). STK performs complex analysis of land, sea, air, and space assets, and shares results in one integrated solution.

In this case STK was used to solve the inter-visibility problems between a ground based observer, the Lunar Mission BW1 spacecraft and the L4 and L5 points. The observer's position was assumed to be the building of the Institute of Space Systems, Stuttgart, Germany (lon.: 9° 00' 30" E / lat.: 48° 40' 25" N).

Since the clouds are very faint, the following constraints had to be taken into account to calculate the possible observation times for the ground based observer to guarantee dark sky:

- max. sun elevation angle: -18°
- max. lunar elevation angle: -1°

For the contact times from the spacecraft to the clouds, a geostationary-transfer orbit (GTO) was simulated as a worst case scenario and sun and lunar exclusion angles of 20° were included.

The simulations show that it is possible to observe the clouds from the Lunar Mission BW1 spacecraft almost any time during the transfer through cis-lunar space. A simulation conducted with a trajectory close to the last orbit before lunar capture (305,000x180,000 km, 21 deg inclination, similar to the SMART-1 capture orbit [14]) showed the spacecraft can get as close as 58,000 km to the clouds. This close proximity will significantly enhance the observation quality.

The contact times of a ground based observer to the L4 and L5 libration points are much shorter. Due to the constraints mentioned above 10 to 15 opportunities are available each month to observe the clouds from the assumed position. The duration lasts from a few minutes up to six hours.

The tables below list the longest contact durations and the equatorial coordinates for each month from February 2007 until February 2009.

OTHER OBSERVATION OPPORTUNITIES

The Study of the Kordylewski Clouds performed by Lunar Mission BW1 shall be accompanied by observations both from ground and from airborne instruments. Especially ground based observation campaigns are ideally suited for Educational and Public Outreach activities. Measurements from Earth are hard to obtain and thus rare. We can raise their number by including the many observers from the amateur astronomers domain. As a first step we have calculated the positions of the Kordylewski Clouds for the upcoming years and will publish favourable observing times to the general public.

A long-run Kordylewski Cloud observing campaign provides an additional training environment for spacecraft mission controllers and mission designers.

Some of the best previous results regarding the Lunar Libration Clouds were accomplished with NASA’s Kuiper airborne observatory (KAO) [11]. Therefore using the new NASA/DLR airborne observatory SOFIA (Stratospheric Observatory for Infrared Astronomy) will be an excellent choice for future studies. We propose SOFIA observations for mission preparation as well as coordinated ground-based and airborne observations during the cruise phase of the Lunar Mission BW1. The German SOFIA activities are operated and coordinated by the German SOFIA Institute (DSI) located at the Institute of Space Systems (IRS), Stuttgart.

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IRS - L4

Month		Access No	Start Date and Time [UTCG]				End Date and Time [UTCG]				Duration [min]	Begin				End			
												RA [HMS]		Dec [DMS]		RA [HMS]		Dec [DMS]	
Feb	07	21	19	Feb	07	19:31:12.124	20	Feb	07	01:37:26.947	366,25	03:47:11.5071	E	25:08:24.4127	N	04:03:32.2076	E	26:00:19.5404	N
Mar	07	34	20	Mar	07	19:54:17.331	21	Mar	07	01:47:40.379	353,38	05:33:36.0615	E	28:31:39.7062	N	05:50:28.1167	E	28:35:00.7690	N
Apr	07	45	18	Apr	07	20:20:11.156	19	Apr	07	01:18:21.505	298,17	07:20:14.5582	E	26:32:27.9220	N	07:33:50.6530	E	25:55:27.1845	N
May	07	58	18	May	07	21:54:41.988	19	May	07	00:38:58.750	164,28	09:56:52.5887	E	14:01:13.5207	N	10:02:57.9996	E	13:19:44.7843	N
Jun	07	---	NO CONTACT								---	NO CONTACT							
Jul	07	69	22	Jul	07	22:08:39.359	23	Jul	07	01:04:42.853	176,06	18:31:19.6989	E	27:46:36.9640	S	18:37:49.1656	E	27:37:28.5204	S
Aug	07	81	21	Aug	07	21:27:19.027	22	Aug	07	02:23:12.281	295,89	20:46:07.5233	E	20:36:23.9038	S	20:56:04.4908	E	19:44:22.4612	S
Sep	07	94	19	Sep	07	20:53:01.814	20	Sep	07	02:45:51.521	352,83	22:03:00.8558	E	12:47:12.7207	S	22:14:08.5697	E	11:28:18.7593	S
Oct	07	111	18	Oct	07	20:50:19.015	19	Oct	07	02:52:34.789	362,26	23:18:12.5846	E	03:11:16.2898	S	23:29:23.5077	E	01:41:49.5730	S
Nov	07	125	14	Nov	07	18:41:14.277	15	Nov	07	00:41:58.981	360,75	23:02:31.1182	E	05:01:55.4734	S	23:13:28.6831	E	03:35:42.7916	S
Dec	07	140	12	Dec	07	17:43:36.962	12	Dec	07	23:43:46.336	360,16	23:34:02.0863	E	00:35:21.1902	S	23:45:06.0180	E	00:52:47.6293	N
Jan	08	158	13	Jan	08	21:52:06.656	14	Jan	08	03:53:28.198	361,36	03:40:15.0200	E	24:54:28.8984	N	03:55:05.2816	E	25:38:44.4494	N
Feb	08	169	9	Feb	08	19:39:23.341	10	Feb	08	01:41:05.517	361,70	03:20:03.2018	E	23:49:31.4379	N	03:34:52.7531	E	24:41:50.9849	N
Mar	08	183	9	Mar	08	20:01:25.018	10	Mar	08	01:54:27.120	353,04	05:05:11.6765	E	27:46:22.6085	N	05:21:14.6968	E	27:56:13.8207	N
Apr	08	194	7	Apr	08	20:28:00.378	8	Apr	08	01:32:21.150	304,35	06:53:35.5215	E	26:26:55.8933	N	07:07:27.7877	E	25:54:49.9241	N
May	08	208	6	May	08	21:06:04.178	7	May	08	00:36:29.982	210,43	08:35:37.6957	E	20:12:03.8531	N	08:44:29.9065	E	19:27:18.5693	N
Jun	08	219	6	Jun	08	22:42:31.960	6	Jun	08	23:58:35.900	76,07	11:55:17.2635	E	03:01:14.1534	S	11:57:59.2784	E	03:22:11.6235	S
Jul	08	229	10	Jul	08	22:30:57.969	11	Jul	08	00:29:10.495	118,21	17:48:49.5302	E	27:29:22.5809	S	17:53:17.9934	E	27:26:52.5330	S
Aug	08	241	9	Aug	08	21:44:35.211	10	Aug	08	01:56:31.606	251,94	20:06:56.6769	E	22:01:25.9600	S	20:15:27.5526	E	21:24:05.9877	S
Sep	08	253	7	Sep	08	21:00:01.021	8	Sep	08	02:37:13.207	337,20	21:23:45.2836	E	15:14:26.0124	S	21:34:16.0638	E	14:07:56.1699	S
Oct	08	270	7	Oct	08	21:46:33.628	8	Oct	08	03:43:34.024	357,01	23:20:33.5222	E	01:08:49.2810	S	23:31:10.8986	E	00:13:34.7225	N
Nov	08	283	3	Nov	08	19:34:12.304	4	Nov	08	01:29:59.859	355,79	23:02:50.0443	E	03:13:39.6574	S	23:13:17.0604	E	01:53:36.9904	S
Dec	08	305	5	Dec	08	23:09:35.993	6	Dec	08	05:04:32.711	354,95	02:43:56.0432	E	21:13:28.5446	N	02:56:59.3060	E	22:07:37.1831	N
Jan	09	321	2	Jan	09	22:08:58.746	3	Jan	09	04:04:29.401	355,51	03:20:13.6704	E	23:38:42.2764	N	03:33:42.0994	E	24:20:55.3509	N
Feb	09	348	26	Feb	09	19:00:28.516	27	Feb	09	00:55:32.622	355,07	03:41:24.3413	E	24:39:50.9353	N	03:55:20.9804	E	25:15:16.9709	N

Table 1. Longest contact durations from the IRS building to the L4 Libration Point

IRS - L5

Month		Access No	Start Date and Time [UTCG]				End Date and Time [UTCG]				Duration [min]	Begin				End			
												RA [HMS]		Dec [DMS]		RA [HMS]		Dec [DMS]	
Feb	07	23	11	Feb	07	20:58:37.403	12	Feb	07	03:02:13.189	363,60	12:30:21.0485	E	05:29:55.8666	S	12:41:35.6802	E	06:58:50.3978	S
Mar	07	38	11	Mar	07	19:52:45.082	12	Mar	07	01:52:33.362	359,81	12:57:43.4278	E	09:06:27.6894	S	13:08:58.1515	E	10:31:07.9201	S
Apr	07	50	9	Apr	07	20:05:40.776	10	Apr	07	01:29:49.053	324,14	14:18:24.7386	E	18:13:46.8680	S	14:29:39.4842	E	19:17:51.1927	S
May	07	64	8	May	07	21:09:25.578	9	May	07	00:37:37.781	208,20	15:53:22.9911	E	25:19:59.8812	S	16:01:35.0491	E	25:45:04.4958	S
Jun	07	76	8	Jun	07	22:47:02.997	8	Jun	07	23:58:45.623	71,71	19:45:33.9525	E	24:58:23.1333	S	19:48:33.8573	E	24:48:21.6295	S
Jul	07	83	11	Jul	07	22:29:17.631	12	Jul	07	00:29:57.037	120,66	00:52:05.8170	E	08:57:12.5220	N	00:56:24.0795	E	09:29:28.4745	N
Aug	07	96	10	Aug	07	21:31:33.099	11	Aug	07	01:52:36.557	261,06	03:14:12.8249	E	23:15:47.6796	N	03:24:24.8600	E	23:56:25.9619	N
Sep	07	108	8	Sep	07	20:45:12.655	9	Sep	07	02:14:02.876	328,84	04:51:26.2145	E	27:46:10.3647	N	05:04:38.5629	E	28:02:17.5650	N
Oct	07	124	8	Oct	07	21:37:26.811	9	Oct	07	03:38:05.448	360,64	07:28:08.8262	E	25:42:44.7558	N	07:41:18.8615	E	25:01:52.0196	N
Nov	07	137	4	Nov	07	19:29:58.658	5	Nov	07	01:29:40.191	359,69	07:10:38.5108	E	26:17:53.1546	N	07:23:56.3186	E	25:42:52.5967	N
Dec	07	153	2	Dec	07	18:29:10.772	3	Dec	07	00:27:52.341	358,69	07:47:01.5322	E	24:16:41.3064	N	07:59:48.8499	E	23:29:40.7862	N
Jan	08	189	31	Jan	08	20:49:40.173	1	Feb	08	02:49:56.504	360,27	11:52:25.8723	E	02:10:06.7351	S	12:02:55.6606	E	03:33:19.9395	S
Feb	08	206	28	Feb	08	19:40:31.333	29	Feb	08	01:39:45.088	359,23	12:17:56.7684	E	05:32:46.0744	S	12:28:30.5000	E	06:54:18.5842	S
Mar	08	223	28	Mar	08	19:40:50.508	29	Mar	08	01:20:06.472	339,27	13:30:25.9827	E	14:14:54.5221	S	13:41:04.4248	E	15:23:18.2251	S
Apr	08	237	27	Apr	08	20:58:38.278	28	Apr	08	01:03:30.722	244,87	15:44:45.8792	E	24:58:15.0358	S	15:53:51.1477	E	25:24:16.1684	S
May	08	252	27	May	08	22:08:33.411	28	May	08	00:06:05.375	117,53	18:20:39.8824	E	27:02:55.1982	S	18:25:24.4023	E	26:56:30.3919	S
Jun	08	262	30	Jun	08	23:02:09.622	30	Jun	08	23:53:33.710	51,40	00:26:58.6268	E	07:13:17.1880	N	00:28:54.4069	E	07:27:41.2438	N
Jul	08	271	30	Jul	08	21:58:20.716	31	Jul	08	01:30:02.636	211,70	02:53:15.3249	E	22:04:00.8128	N	03:02:11.6562	E	22:40:55.5652	N
Aug	08	280	28	Aug	08	21:14:13.221	29	Aug	08	02:37:45.779	323,54	04:33:32.2161	E	26:52:16.2885	N	04:47:41.2656	E	27:10:57.2209	N
Sep	08	292	26	Sep	08	21:04:22.135	27	Sep	08	02:59:06.520	354,74	06:18:20.7229	E	26:55:14.1358	N	06:33:06.2240	E	26:32:58.7400	N
Oct	08	306	24	Oct	08	20:05:32.820	25	Oct	08	02:02:02.536	356,50	06:59:47.9318	E	25:24:42.1492	N	07:13:50.7021	E	24:47:44.7732	N
Nov	08	320	21	Nov	08	19:10:23.260	22	Nov	08	01:05:54.632	355,52	07:40:39.6277	E	23:07:40.7718	N	07:53:56.7315	E	22:17:48.7051	N
Dec	08	339	23	Dec	08	22:51:50.433	24	Dec	08	04:47:07.625	355,29	11:30:39.1745	E	00:43:36.5496	S	11:41:08.2453	E	02:03:49.8338	S
Jan	09	352	19	Jan	09	20:42:11.056	20	Jan	09	02:37:35.867	355,41	11:15:21.2273	E	01:05:42.6594	N	11:25:54.5205	E	00:15:12.5535	S
Feb	09	365	16	Feb	09	19:35:24.366	17	Feb	09	01:30:51.014	355,44	11:42:47.7303	E	02:24:36.0414	S	11:53:25.6327	E	03:45:19.5205	S

Table 2. Longest contact durations from the IRS building to the L5 Libration Point