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Laser Observations of the Moon:

Normal Points for 1973

J. Derral Mulholland and Peter J. Shelus
McDonald Observatory and Dept. of Astronomy
University of Texas at Austin, Austin, Texas 78712

Eric C. Silverberg
McDonald Observatory, Fort Davis, Texas 79735

Abstract

McDonald Observatory lunar laser ranging observations for 1973 are presented in the form of compressed normal points and amendments for the 1969-1972 data set are given. Observations of the reflector mounted on the Soviet roving vehicle Lunakhod 2 have also been included.

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INTRODUCTION

The lunar laser ranging experiment (LURE) project at McDonald Observatory has provided beyond a doubt the unique opportunity to acquire successfully precise ranging data for the Earth-Moon system (Bender et al 1973, Silverberg 1974). This is the third paper in a series devoted to the observations themselves. The first (Abbot et al 1973: Paper I) presented the observations for 1969-1971 and described the processes which were used to filter the observations from the noise and to compress these observations into normal points; the second (Shelus et al 1975: Paper II) continued the observations through 1972, presented a list of data amendments and discussed the precise role played by the geometry of the McDonald 2.7 meter telescope in the proper use of the data. The processes described therein remain valid and should be consulted by the interested user before applying the data to analysis. We present here the observations for 1973.

I. DATA AMENDMENTS 1969-1972

As reported in Papers I and II it has been possible to detect spurious offsets in the measured time delay of an observation. Initially, the anomalies which were found were caused by non-random counter errors which were integer multiples of 50 nsec, the basic counter period. With the continuing improvement of the physical model of the lunar orbit and rotation the discrimination has been able to reach finer and finer levels. Largely through the efforts of Williams (1975), examples of other failure modes which produce spurious offsets in the measured time delay of nearly arbitrary size have been found. Additional points in our previous data sets have been flagged as being suspicious. These are tabulated in Table I.

Care should be exercised in the use of these points for any analysis activity.

The reality of this discrimination is effectively proven by the fact that it is possible in most cases to go back to original observing logs and equipment documentation to isolate previously unsuspected anomalies on the basis of these spurious offsets. It has been proposed to begin a reconsideration of all raw ranging data in an effort to recover from anomalies such as those mentioned above. This effort will insure that early data have not been overlooked, will take advantage of the full accuracy available in the observations and will provide as wide a data base as possible.

II. OBSERVATIONS 1973

The normal-point data for the 1973 observations are presented in Table II. Complete definitions are given in Papers I and II. The 442 normal data points contained here represent some 4281 photons such that an average point represents about 9.7 signal photon returns. The distribution of the 1973 data with respect to reflector is given in Table III. Figure 1 presents histograms of the distribution of the McDonald laser data with respect to the classical fundamental arguments of the lunar motion. The effect of the 1973 data is indicated explicitly. The distribution of the 1973 normal points is essentially identical to the distribution of the earlier data. A level distribution for the 1969-1973 data would have 61 points per 20° interval.

With the increasing importance of the lunar laser ranging experiment toward the solution of geophysically interesting problems, i.e.,

earth rotation and precise position determination, it is also informative to note the distribution of observations with respect to parameters that govern observation site location. Figure 2 presents histograms of the distribution of the McDonald data with respect to the lunar declination and local hour angle. The division interval in each case is 5° . Again, the data for 1973 is illustrated explicitly. The distribution with respect to the lunar declination shows: a) the moon spends most time at extreme declinations; b) since McDonald Observatory is in the Northern hemisphere observations are easier to obtain when the moon is at northern declinations; c) as the ascending node of the lunar orbit regresses toward the autumnal equinox, the total range of lunar declination decreases. The gross structure of the distribution of observations with respect to local hour angle is due to the fact that ranging is typically scheduled at McDonald for three 45 minute sessions per day, when the moon is at -3, 0 and +3 hours from the meridian. Additionally one can note that successful ranging to the moon is easier for smaller zenith distances, i.e., at meridian passage where one is firing through less air mass.

III. LUNAKHOD 2 OBSERVATIONS

The second of two French-built retrorreflector arrays was deployed on the lunar surface on the Soviet roving vehicle Lunakhod 2, landed by the Luna 21 spacecraft in January, 1973. Shortly after, it was observed by a Franco-American effort at the McDonald Observatory (Abalakin et al, 1973). A second series of McDonald observations was obtained a month later, after a considerable traverse by the rover. Due to the motion, these observations are of no practical value beyond giving

assurance that the reflector array was usable and permitting some very tenuous discussion of the use of very short data arcs for determining reflector coordinates (Mulholland et al, 1973). For completeness these observations have been presented in Table IV in compatible format with the other 1973 observations. These appear with the reflector identifier 4.

In the months following these first acquisitions, Lunakhod 2 could not be recovered. Interest was revived when the Soviet ranging team reported successful, but difficult, observations during the summer months of 1973. Operations were resumed at McDonald at the earliest opportunity (Barker et al, 1975) and after one unsuccessful night, the array was acquired on 1973 November 16. Weather and operational considerations prevented further observations of Lunakhod 2 during 1973 from McDonald. This one observation has been included in the regular data of Table II.

IV. ACKNOWLEDGMENTS

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has contributed significantly to the amendments of Table I.

The raw and filtered data upon which the normal points are based are available to all interested U.S. scientists from the National Space Science Data Center, Code 601, Goddard Space Flight Center, Greenbelt, Maryland 20771. Foreign scientists should contact the COSPAR World Data Center, at the same address.

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Table I. Suspect points from the list given in Table II of Paper I
and II. T^* is the equivalent Julian date of observation.

T^* (UTC)	
2440000+	
820.9957076723	
1103.5450520877	Paper I
1195.6293865652	
1223.5264236034	

1399.7008522612	
1399.7259837839	
1410.8993904243	
1411.0089236030	Paper II
1411.0252864501	
1417.0826562438	
1500.0826064827	
1522.7985301120	
1562.0130903073	
1647.9028472536	

Table II. Observational normal points. Definitions of T^* , τ^* , ϵ^* , N , R , P are given in Paper I. Observatory code is adopted from IAU Minor Planet Circulars (711=McDonald Observatory). Reflector code: 0=Apollo 11, 2=Apollo 14, 3=Apollo 15, 4=Lunakhod 2.

T^* (UTC)	τ^*	ϵ^*	N	R	P	Obs	Refl
2440000+	TAI sec	nsec		nsec	mbar	code	code
1694.6679456100	2.4619712416	.9	6	19.7	801.2	711	3
1695.4668557177	2.4323483032	.8	9	14.9	798.6	711	3
1695.5355121600	2.4255623668	1.1	4	13.0	798.6	711	3
1695.7021478245	2.4334714203	.9	7	18.5	798.6	711	3
1696.4888045703	2.4091271645	.7	14	15.4	799.9	711	3
1696.5042882008	2.4054768679	.9	6	14.6	799.9	711	2
1696.5110267923	2.4055451094	.9	7	14.3	799.9	711	0
1696.6427314887	2.3998362494	.8	9	13.1	801.2	711	3
1696.6463604869	2.3984718066	.7	11	13.2	801.2	711	2
1696.6502157807	2.3996502858	.7	14	13.3	801.2	711	0
1696.7393024058	2.4083657023	.7	11	17.8	801.2	711	3
1696.7441435252	2.4075162094	.9	6	18.2	801.2	711	2
1696.7535532472	2.4099212190	1.2	3	19.3	801.2	711	0
1697.5061363702	2.3923476277	.7	11	16.8	803.9	711	3
1697.5147443242	2.3897379039	.7	11	16.2	803.9	711	2
1697.5260347280	2.3887619485	1.0	5	15.4	803.9	711	0
1697.6359935962	2.3799371028	.7	13	12.6	801.2	711	3
1697.6467129689	2.3793038286	.7	15	12.6	801.2	711	0
1697.7668055609	2.3874403146	.6	18	16.3	801.2	711	3
1699.5972951197	2.3759196826	.8	17	16.6	798.6	711	3
1699.7472019730	2.3666599176	.8	12	12.7	798.6	711	3

1701.6975381992	2.4019265454	.7	10	16.0	798.6	711	3
1701.8427033775	2.3980674064	.9	7	13.1	795.9	711	3
1701.9612786157	2.4141396781	1.0	5	19.4	795.9	711	3
1702.7531336845	2.4299504438	.8	8	15.5	787.9	711	3
1702.9051736146	2.4312281830	.8	8	14.0	786.6	711	3
1706.9917786120	2.5876237949	1.3	5	16.9	797.2	711	3
1707.9838958334	2.6194637377	1.3	5	18.4	793.2	711	3
1708.9664444438	2.6465487025	1.3	5	22.4	793.2	711	3
1727.5509249091	2.4138228328	1.2	11	16.4	793.2	711	3
1727.5637375352	2.4116955169	1.3	5	15.5	793.2	711	0
1728.6098324525	2.4192591626	1.0	44	15.5	797.2	711	3
1728.7390625345	2.4138293489	1.1	16	12.9	795.9	711	3
1728.8428680898	2.4243753271	1.1	20	16.7	795.9	711	3
1729.6389520537	2.4358824482	1.2	11	16.5	797.2	711	3
1729.6500278116	2.4343334403	1.3	5	15.8	797.2	711	0
1731.8246632277	2.4832306129	1.2	10	14.1	791.9	711	3
1731.9252662360	2.4931988001	1.3	6	17.4	791.9	711	3
1732.8683021145	2.5180218506	1.2	10	15.1	798.6	711	3
1738.0637558141	2.6588994472	1.3	6	23.2	793.2	711	3
1739.1318055818	2.6664399533	1.2	9	27.4	798.6	711	3
1740.0002387408	2.6624967395	1.2	8	28.1	799.9	711	2
1740.0070139142	2.6621607107	1.2	10	27.0	799.9	711	3
1740.1084375250	2.6579068739	1.2	11	23.1	802.6	711	3
1753.4625663085	2.4226781403	1.2	11	14.1	794.6	711	3
1753.6673727057	2.4279402899	1.3	6	15.8	794.6	711	3
1755.5222970277	2.4429743670	.7	13	15.3	786.6	711	3
1755.5374479358	2.4409801958	.7	10	14.6	786.6	711	0
1755.6402257135	2.4374367949	.7	14	12.8	787.9	711	3
1755.7685286648	2.4505698373	.8	8	17.7	789.2	711	3
1756.5693750184	2.4561357839	.8	9	15.2	786.6	711	3
1756.6829861294	2.4520112376	.9	6	13.0	789.2	711	3

1757.7212400970	2.4703313332	.7	14	13.4	795.9	711	3
1757.8454514064	2.4854757930	1.2	3	19.9	795.9	711	3
1758.7155874088	2.4914821347	.6	24	13.9	801.2	711	3
1758.8761284964	2.5079398251	.9	6	21.0	799.9	711	3
1759.8978472455	2.5315445827	.9	10	21.3	791.9	711	3
1763.9288046036	2.6285905849	.7	10	20.5	791.9	711	3
1763.9456365941	2.6300102601	.9	6	21.3	791.9	711	0
1764.8228183067	2.6518009549	1.0	6	28.7	789.2	711	3
1765.0095625194	2.6523146784	1.1	5	25.6	786.6	711	3
1767.9999392534	2.6583172765	.8	12	22.9	791.9	711	3
1769.0572916826	2.6420295809	.8	8	21.4	787.9	711	3
1769.1357248403	2.6435704248	.8	8	24.4	787.9	711	3
1770.0185953431	2.6234102228	.9	11	23.7	789.2	711	3
1770.0442882094	2.6205704052	.9	8	21.6	789.2	711	3
1770.1093687018	2.6170037829	.9	11	20.1	790.6	711	3
1771.1310532549	2.5851317546	.9	9	18.5	789.2	711	3
1771.1377691112	2.5836258988	1.2	4	18.6	789.2	711	2
1771.1531597361	2.5847041898	1.5	2	18.7	789.2	711	3
1781.6406828733	2.4225235023	.7	9	17.3	795.9	711	0
1782.4539496551	2.4320734402	.9	8	14.4	797.2	711	0
1782.4639930579	2.4317324349	.8	13	14.0	797.2	711	3
1782.5516464142	2.4293084265	.6	12	12.7	797.2	711	0
1782.5575925946	2.4299459027	1.2	3	12.7	797.2	711	3
1782.5738859971	2.4303385999	.6	12	12.9	797.2	711	0
1782.7032465287	2.4475482014	1.4	2	20.0	797.2	711	0
1783.5063078605	2.4542630115	.7	9	14.1	795.9	711	3
1783.5320269001	2.4524714474	.7	8	13.4	795.9	711	0
1783.6220833238	2.4544049368	.7	9	13.2	797.2	711	3
1783.7231219345	2.4679800324	.7	10	18.5	797.2	711	3
1784.7492230794	2.4910955703	.8	8	18.3	797.2	711	3
1784.7580208228	2.4928656992	.7	11	19.3	797.2	711	2

1784.7661487161	2.4941629313	.7	12	20.4	797.2	711	0
1785.6756168187	2.5030307292	.6	17	13.8	794.6	711	3
1785.6839687387	2.5034516349	.7	10	14.0	794.6	711	0
1785.7580642247	2.5122924232	.7	12	17.1	795.9	711	3
1786.5626388770	2.5338550857	.8	9	19.0	794.6	711	3
1786.6898148027	2.5276996823	.9	6	14.4	795.9	711	3
1787.6197643721	2.5564548855	1.1	14	18.2	790.6	711	3
1787.7273343886	2.5534650822	1.1	13	15.3	790.6	711	3
1788.7599021326	2.5786452681	.9	11	16.5	794.6	711	3
1788.8631249862	2.5902365488	1.0	6	23.3	794.6	711	3
1790.6823262740	2.6314382602	.9	11	29.0	791.9	711	3
1790.8169907256	2.6246592901	.9	9	19.3	791.9	711	3
1790.8251944289	2.6252491482	.9	10	19.4	791.9	711	2
1790.8339756791	2.6255214268	.9	8	19.6	791.9	711	0
1792.7824696017	2.6620169273	.8	8	27.3	786.6	711	3
1792.7932334902	2.6610088378	.8	8	26.0	786.6	711	2
1792.8011047810	2.6604770619	.7	11	25.0	786.6	711	0
1792.8132161288	2.6595823637	.8	8	23.9	786.6	711	3
1792.9498674072	2.6625108709	.7	11	25.7	786.6	711	3
1794.8195895152	2.6770125642	.6	28	36.0	794.6	711	3
1794.8287847038	2.6758018515	.8	8	33.2	794.6	711	0
1794.8333289745	2.6746974518	.8	8	32.2	794.6	711	2
1794.8427628756	2.6740234955	.9	7	30.0	794.6	711	3
1794.9466353952	2.6678361616	.7	10	22.4	794.6	711	3
1795.8796527558	2.6674068989	.7	10	28.4	794.6	711	3
1795.8873533732	2.6657407503	.8	9	27.3	794.6	711	2
1795.8940397349	2.6656928131	.8	8	26.2	794.6	711	0
1795.9061679076	2.6644772671	.7	11	24.9	794.6	711	3
1796.0231001761	2.6614854601	.9	7	22.9	794.6	711	3
1797.0063194215	2.6446406399	.9	10	20.5	791.9	711	3
1797.0358432311	2.6434213512	1.0	7	20.8	791.9	711	2

1797.0528529862	2.6448765006	1.0	6	21.4	791.9	711	3
1797.1166249766	2.6494382895	.9	10	27.9	791.9	711	3
1797.9364096985	2.6296618289	.7	10	25.8	791.9	711	3
1797.9438730823	2.6273153386	.6	11	24.8	791.9	711	2
1798.027159021	2.6202322338	.7	9	19.2	791.9	711	3
1798.1113194204	2.6207723535	.8	6	21.3	791.9	711	3
1810.5045694285	2.4164991595	.7	10	12.8	795.9	711	0
1810.5134770086	2.4173357971	.9	7	12.9	795.9	711	3
1810.6266468100	2.4309700415	.9	7	17.4	797.2	711	0
1811.4219791391	2.4536503915	.7	10	16.1	798.6	711	3
1811.6671373179	2.4657333323	.8	9	18.4	798.6	711	3
1813.4860563635	2.5227766178	1.2	8	18.0	798.6	711	3
1813.6244212701	2.5195000563	1.2	12	14.3	798.6	711	3
1813.7491589255	2.5376854316	1.2	9	20.6	798.6	711	3
1819.7317650269	2.6612470491	.7	12	23.1	802.6	711	3
1819.8700954693	2.6652430710	.8	8	26.0	801.2	711	3
1820.7443263729	2.6724919351	.7	10	26.1	798.6	711	3
1820.7663237686	2.6709006472	.8	8	24.0	798.6	711	3
1820.8843784546	2.6723235060	.7	10	24.8	799.9	711	3
1821.7441666511	2.6806850285	.7	10	32.6	797.2	711	3
1822.8377673466	2.6732642203	.7	10	23.6	797.2	711	3
1822.9925247880	2.6771400743	.8	7	29.6	797.2	711	3
1823.8134166532	2.6710162819	.7	10	29.7	797.2	711	3
1824.0243749884	2.6673741898	1.1	4	27.5	797.2	711	3
1826.9416087832	2.5973490914	.8	6	19.2	795.9	711	3
1826.9738628344	2.5921427587	1.0	4	17.5	795.9	711	2
1827.0716559702	2.5910594156	.6	13	17.7	795.9	711	3
1839.5278949647	2.4399673862	.9	8	13.9	801.2	711	3
1842.5702003227	2.5574014617	.7	13	15.7	799.9	711	3
1842.588529881	2.5580648097	1.1	4	15.8	799.9	711	0
1842.6146701413	2.5600486508	.9	6	16.3	799.9	711	3

1842.7011607165	2.5724005936	.9	7	23.0	799.9	711	3
1843.6082407438	2.5916771672	.8	9	16.9	798.6	711	3
1843.7283680586	2.6050344586	.9	7	24.9	799.9	711	3
1844.5524236150	2.6226149465	.7	10	21.6	795.9	711	3
1845.6716049431	2.6428566037	.8	9	19.7	797.2	711	3
1845.7761607192	2.6520617218	.9	7	27.3	795.9	711	3
1846.8077264642	2.6677094336	.9	8	29.3	797.2	711	3
1848.6779513967	2.6799331881	.8	12	28.5	798.6	711	3
1848.8548090357	2.6796777219	.9	8	27.6	797.2	711	3
1849.9035590369	2.6802318461	.7	10	29.4	797.2	711	3
1850.7627286210	2.6727026550	.7	10	24.8	797.2	711	3
1850.7845734221	2.6708110489	.9	7	22.9	797.2	711	3
1850.9278255308	2.6728156644	.8	8	26.4	798.6	711	3
1850.9521478273	2.6746731108	.9	7	30.9	798.6	711	2
1851.7798611217	2.6635494673	.9	7	25.0	795.9	711	3
1851.8905064305	2.6571209474	.8	9	20.1	797.2	711	3
1856.0743055834	2.5573687326	.9	6	16.9	803.9	711	3
1859.0779653084	2.4377415718	.7	10	13.1	801.2	711	3
1859.0924355466	2.4353005905	.9	7	13.1	799.9	711	2
1859.1134028082	2.4365914201	1.1	4	13.1	799.9	711	3
1859.1710011880	2.4381840963	.9	6	14.5	801.2	711	3
1859.9867235040	2.4162201557	.9	6	18.3	797.2	711	3
1860.0667916983	2.4036720483	.7	10	13.6	795.9	711	3
1860.1162226710	2.3996190740	.9	6	12.8	795.9	711	3
1860.1322014207	2.3973525096	1.0	5	12.8	795.9	711	2
1870.5496528193	2.5561005756	1.1	5	16.8	797.2	711	0
1870.5766022236	2.5588275871	1.0	7	17.7	797.2	711	3
1871.5540336069	2.5923387039	.9	6	17.8	797.2	711	3
1872.7015234806	2.6354270866	.8	8	28.6	799.9	711	3
1873.5188492501	2.6512490545	.9	7	26.5	799.9	711	3
1873.7429282846	2.6595368242	.9	6	33.8	799.9	711	3

1888.1665625610	2.4194018511	1.2	8	14.4	803.9	711	3
1888.1890914951	2.4198715537	1.3	6	15.5	803.9	711	2
1888.9875000615	2.4023627618	1.4	4	16.7	801.2	711	3
1889.0833226851	2.3905693610	1.1	18	12.9	802.6	711	3
1901.5077569961	2.6459425806	1.0	5	23.0	798.6	711	3
1902.5788889405	2.6606731065	.7	15	22.4	797.2	711	3
1902.5919151154	2.6606123067	.7	13	22.3	797.2	711	2
1902.6847601526	2.6662951034	.7	11	27.7	799.9	711	3
1902.6921511344	2.6670600168	.8	8	29.1	799.9	711	0
1902.7019329177	2.6683292133	1.2	3	31.0	799.9	711	2
1904.6044476500	2.6678016187	.7	11	24.2	799.9	711	3
1904.6893276430	2.6653982022	.7	13	22.2	799.9	711	3
1907.6304167185	2.6347199383	.7	10	29.6	802.6	711	3
1907.6391111627	2.6329164886	.7	10	27.5	802.6	711	0
1907.7532743572	2.6211312306	.7	10	18.1	803.9	711	3
1907.7592361629	2.6197167941	.8	8	18.1	803.9	711	2
1907.8787847737	2.6268947858	.8	9	25.0	801.2	711	3
1908.6867604690	2.6082584869	.7	10	22.2	802.6	711	3
1908.6952633625	2.6055946070	.7	12	21.3	802.6	711	2
1908.8055980462	2.5980092505	.8	9	16.7	802.6	711	3
1908.8198341568	2.5977211455	.8	9	16.9	802.6	711	0
1908.9264453647	2.6062952932	.8	8	25.4	801.2	711	3
1909.7228125527	2.5832397398	.7	11	19.7	801.2	711	3
1909.7301543741	2.5806291523	.8	9	19.1	801.2	711	2
1909.7356076921	2.5809767775	1.5	2	18.6	801.2	711	0
1909.8495928564	2.5736201884	.7	11	15.7	801.2	711	3
1909.8608724492	2.5734613772	.8	8	15.9	801.2	711	0
1909.9501493579	2.5809935187	.7	10	21.9	799.9	711	3
1910.7414815358	2.5600962415	.8	9	19.3	801.2	711	3
1910.7506306093	2.5581812375	.7	10	18.4	801.2	711	0
1910.7583889427	2.5557943909	.7	10	17.0	801.2	711	2

1910.8762847760	2.5484016433	.7	11	14.7	801.2	711	3
1910.9645107862	2.5538327651	.7	11	18.5	801.2	711	3
1911.7729236662	2.5346890280	1.3	5	18.0	801.2	711	3
1911.9147787007	2.5231878971	1.2	8	14.0	801.2	711	3
1911.9209592562	2.5228881599	1.2	8	14.1	801.2	711	0
1912.8039047272	2.5096972303	1.2	11	17.1	801.2	711	3
1912.8116840831	2.5079927835	1.2	8	16.5	801.2	711	0
1912.8158854720	2.5061472748	1.4	4	16.3	801.2	711	2
1912.9286779722	2.4981105003	1.2	10	13.3	801.2	711	3
1912.9366944997	2.4963841309	1.2	10	13.4	801.2	711	2
1912.9902683634	2.4999000376	1.2	11	14.5	801.2	711	3
1913.8464047273	2.4836122264	.7	11	15.9	801.2	711	3
1913.9816363407	2.4736179779	.8	8	13.1	801.2	711	3
1913.9878611669	2.4721110121	.7	10	13.2	801.2	711	2
1915.9986359704	2.4282326217	.7	14	12.9	803.9	711	2
1916.0207778354	2.4285131915	1.0	5	12.7	803.9	711	3
1916.1010000579	2.4286057304	.7	10	13.6	802.6	711	2
1916.9145776046	2.4248583676	1.0	6	19.1	803.9	711	2
1917.0004591632	2.4123501739	.9	9	13.7	802.6	711	2
1917.0138108225	2.4121524355	.9	8	13.3	802.6	711	3
1917.0940779905	2.4079580838	.9	9	12.7	802.6	711	2
1917.9639583929	2.4091842978	.9	10	18.4	801.2	711	3
1918.0323232922	2.3994063618	.9	11	14.0	802.6	711	3
1918.0461178513	2.3971827251	.8	12	13.6	802.6	711	2
1918.1588021432	2.3950169518	.8	12	13.0	801.2	711	3
1919.0155625605	2.3977872828	1.1	5	17.8	801.2	711	2
1919.0913472827	2.3882603801	1.1	5	13.6	801.2	711	2
1928.4675347894	2.6185501444	1.3	3	20.9	798.6	711	0
1928.5790347893	2.6282851254	1.1	5	28.7	799.9	711	0
1929.4485764566	2.6433744221	.9	7	24.0	799.9	711	0
1929.5762413875	2.6464476253	.8	8	24.9	799.9	711	0

1929.5884105613	2.6478846944	.8	9	26.1	799.9	711	3
1929.6011264103	2.6493066491	.9	6	28.1	799.9	711	0
1930.4928125686	2.6579449167	.7	9	23.8	798.6	711	0
1931.5151667359	2.6643267640	.7	15	24.5	798.6	711	3
1931.5399840434	2.6626266812	.7	13	22.9	798.6	711	0
1931.5540919495	2.6623006001	.7	13	22.4	798.6	711	3
1931.6639861805	2.6665185762	.7	10	27.1	799.9	711	3
1933.5706250703	2.6487491328	1.2	9	23.1	795.9	711	3
1933.5755972926	2.6473291438	1.2	10	22.7	795.9	711	2
1933.5809722926	2.6474490668	1.3	5	22.3	795.9	711	0
1933.7267551210	2.6470306383	1.2	11	23.7	795.9	711	3
1933.7328299315	2.6473519116	1.4	4	24.5	795.9	711	0
1933.7527361816	2.6496069546	1.2	10	27.3	795.9	711	3
1934.5706818888	2.6332982712	.7	11	25.0	797.2	711	3
1934.6905864906	2.6236580430	.8	9	18.6	798.6	711	3
1934.6957008284	2.6224794156	.7	11	18.7	798.6	711	2
1934.7109226898	2.6235887611	.9	7	19.1	798.6	711	0
1934.8028264599	2.6310016343	.7	10	28.2	798.6	711	3
1938.9121557448	2.5185582378	.8	12	17.9	798.6	711	3
1938.9215818638	2.5192639614	.9	9	18.8	798.6	711	0
1938.9311189004	2.5192326942	.9	9	19.7	798.6	711	2
1940.7653611859	2.4750315724	.7	10	15.8	801.2	711	3
1941.0096832344	2.4759596449	.8	8	18.8	801.2	711	3
1941.9183411248	2.4482823688	.8	9	12.8	799.9	711	3
1941.9285996120	2.4479193209	.7	12	12.9	799.9	711	0
1941.9392153527	2.4471814752	1.0	5	13.0	799.9	711	2
1941.9484653526	2.4489225213	.7	10	13.2	799.9	711	3
1942.0159452910	2.4543214177	.8	9	15.7	799.9	711	3
1942.8225174366	2.4447009155	.7	10	16.2	801.2	711	3
1942.8298573285	2.4431754219	.8	9	15.7	801.2	711	0
1942.8434684398	2.4405303127	.8	9	14.9	801.2	711	2

1942.9445392171	2.4343734020	.7	11	12.7	801.2	711	3
1943.0523403534	2.4402435586	.7	10	15.3	802.6	711	3
1943.9936343353	2.4240047681	.6	12	12.6	802.6	711	3
1944.0104514650	2.4238765289	.7	8	12.8	802.6	711	0
1944.0231597981	2.4235718248	.7	10	12.9	802.6	711	2
1944.0278724370	2.4248136388	.7	10	13.0	802.6	711	3
1944.1058179775	2.4316857671	.7	9	15.9	803.9	711	3
1945.9141435963	2.4274306925	.8	9	19.0	799.9	711	2
1945.9246027012	2.4262643279	.8	9	17.9	799.9	711	3
1946.0404262141	2.4139031240	.7	11	12.8	799.9	711	2
1946.9647466060	2.4268334042	.7	10	18.3	798.6	711	3
1958.5268171495	2.6584540344	.9	9	23.0	799.9	711	0
1958.5345287397	2.6590952910	1.0	7	23.3	799.9	711	3
1959.5606173044	2.6614711486	.9	9	22.3	798.6	711	0
1959.5717708537	2.6022571196	1.3	3	22.8	798.6	711	3
1962.5386244881	2.6208749774	.8	13	20.8	801.2	711	3
1962.5424045363	2.6200987294	.9	8	20.5	801.2	711	0
1962.5473154463	2.6185064087	.8	19	20.2	801.2	711	2
1962.5554473688	2.6188607873	.8	17	19.6	801.2	711	3
1963.6575221064	2.5837779840	.5	48	16.4	799.9	711	3
1963.6756250230	2.5820907175	.6	17	16.6	799.9	711	2
1963.6856481714	2.5833864108	1.2	3	16.9	799.9	711	0
1964.5373459438	2.5677453763	.8	16	25.3	794.6	711	3
1964.7308116556	2.5495076618	.8	16	16.0	795.9	711	3
1965.7079383924	2.5140775854	.9	8	14.4	791.9	711	3
1965.7191589750	2.5120474970	.9	9	14.4	791.9	711	2
1965.7320612616	2.5131174745	.9	11	14.5	791.9	711	0
1965.7543383733	2.5136874838	.8	18	14.9	791.9	711	3
1967.8841793184	2.4547534442	.9	11	16.0	793.2	711	3
1968.7021949663	2.4373257013	.8	14	16.2	795.9	711	3
1968.7477257205	2.4299001075	1.0	6	14.0	795.9	711	2

1968.3658767623	2.4276693376	.8	12	13.4	797.2	711	3
1968.8703576650	2.4274302164	.9	10	13.5	797.2	711	0
1968.9435547136	2.4346723728	.9	8	17.1	797.2	711	3
1970.7953754028	2.4096535091	.7	37	14.9	805.2	711	3
1970.8029834677	2.4083095754	.8	13	14.5	805.2	711	0
1970.9028063999	2.4030003597	.8	17	12.7	802.6	711	3
1970.9100294077	2.4020337799	.8	13	12.7	802.6	711	2
1971.0478819717	2.4156267710	.8	15	18.5	802.6	711	3
1971.8204261644	2.4101330881	.9	11	15.8	801.2	711	3
1971.8283459877	2.4087239319	.9	11	15.3	801.2	711	0
1971.8410561623	2.4068516416	.8	12	14.7	801.2	711	2
1972.0057697041	2.4048445692	.8	12	13.5	801.2	711	3
1972.8644589406	2.4143955931	.8	12	15.7	802.6	711	3
1972.8746007231	2.4126648237	.9	8	15.2	802.6	711	2
1972.8846736398	2.4117154673	1.1	5	14.6	802.6	711	0
1972.9874122019	2.4071036645	.8	17	12.7	802.6	711	3
1973.0628409378	2.4116837828	.9	11	14.0	803.9	711	3
1973.9156865824	2.4226725638	.7	22	15.3	805.2	711	3
1973.9249190106	2.4214024834	.9	9	14.9	805.2	711	2
1973.9958996505	2.4170326615	.9	11	12.9	802.6	711	3
1974.0809161617	2.4197251138	.8	13	13.5	803.9	711	3
1974.9282733886	2.4393788898	.9	11	17.6	802.6	711	2
1974.9411400762	2.4376783449	.8	12	16.5	802.6	711	3
1975.0215694744	2.4308650759	.9	10	13.3	802.6	711	2
1975.0919634138	2.4315163298	.9	11	13.2	801.2	711	2
1975.9640400922	2.4561027239	.9	9	18.4	801.2	711	2
1975.9747632881	2.4544682182	.9	11	17.4	801.2	711	3
1976.0626119132	2.4473775475	.9	9	13.6	801.2	711	2
1976.1426966625	2.4493621652	.9	8	13.8	801.2	711	2
1976.9950126573	2.4757072098	.9	11	20.0	799.9	711	2
1977.0043026930	2.4740793743	.8	12	18.9	799.9	711	3

1977.0679224844	2.4678954252	.8	12	14.8	801.2	711	2
1977.1782936818	2.4688602601	1.0	7	14.4	801.2	711	2
1978.0091956335	2.4998974117	.9	6	24.8	801.2	711	2
1978.0315625317	2.4960953040	.8	9	21.0	801.2	711	3
1978.0619010734	2.4927010420	.8	8	17.9	801.2	711	2
1990.6560347607	2.6185316414	1.2	10	20.7	798.6	711	3
1991.4979759376	2.5914512073	1.1	17	19.2	799.9	711	3
1991.5232882334	2.5862733601	.7	10	17.5	799.9	711	2
1991.5432490470	2.5856111410	.9	7	16.6	799.9	711	3
1992.5069167062	2.5569604275	.7	10	19.8	802.6	711	3
1992.5196667063	2.5530115568	1.0	5	18.6	802.6	711	2
1992.5336034347	2.5524121052	.8	9	17.5	802.6	711	3
1992.6735069842	2.5434238309	.8	8	15.5	801.2	711	3
1993.5713418061	2.5100820555	.7	14	16.0	802.6	711	3
1993.5826852254	2.5067486408	.9	6	15.5	802.6	711	2
1993.7192257347	2.5024318472	.7	10	15.1	802.6	711	3
1993.7539263223	2.5047934659	.7	13	16.9	802.6	711	3
1994.5538095645	2.4776710357	1.6	14	19.0	799.9	711	3
1994.5700000407	2.4729025726	1.4	4	17.5	799.9	711	2
1994.7377273137	2.4609762192	1.2	11	14.0	801.2	711	3
1995.5547483053	2.4468352463	1.2	12	22.7	799.9	711	3
1995.7376339702	2.4238346755	1.3	7	13.1	802.6	711	3
1995.7454097637	2.4221712722	1.2	10	13.1	802.6	711	2
1995.7729930971	2.4241922932	1.2	10	13.6	802.6	711	3
1997.7236024613	2.3794718841	1.2	8	14.0	802.6	711	3
1998.7243316285	2.3749509155	.8	16	16.0	801.2	711	3
1998.8827778093	2.3663844769	.9	11	12.9	801.2	711	3
1998.8867951704	2.3662246266	.9	10	12.9	801.2	711	0
1998.8891215592	2.3657890056	.9	10	13.0	801.2	711	2
1998.9012253311	2.3673550145	.7	33	13.2	801.2	711	3
1999.7328906570	2.3813318490	1.2	12	19.2	798.6	711	3

1999.9120625322	2.3685493518	1.2	10	12.7	798.6	711	3
1999.9155650573	2.3683785235	1.2	11	12.8	798.6	711	0
1999.9185208653	2.3682149180	1.2	10	12.8	798.6	711	2
1999.9396979488	2.3699503031	1.2	10	13.1	798.6	711	3
2001.8895139222	2.4033755071	1.2	11	14.5	799.9	711	3
2001.9163541997	2.4015802458	1.2	10	13.6	799.9	711	3
2002.0593854498	2.4073046177	1.2	10	14.5	798.6	711	3
2002.0664881284	2.4081007875	1.3	7	14.9	798.6	711	0
2002.0814004962	2.4104050759	1.3	6	15.7	798.6	711	2
2002.8962951723	2.4318058108	1.2	10	16.6	798.6	711	3
2002.9092032498	2.4314239432	1.1	19	15.8	798.6	711	4
2002.9157595821	2.4297795935	1.2	8	15.4	798.6	711	3
2004.0727500196	2.4563472897	1.2	10	13.8	797.2	711	3
2005.0749179641	2.4853994568	1.2	11	14.3	798.6	711	2
2005.0870660071	2.4852745613	1.2	8	14.3	798.6	711	3
2005.0958838733	2.4861745796	1.2	11	14.4	798.6	711	2
2015.4924930837	2.6740253018	1.1	5	23.4	803.9	711	3
2016.4715625287	2.6626032198	1.0	7	18.9	802.6	711	3
2016.4865972509	2.6628258139	.9	9	19.5	802.6	711	0
2016.5499242711	2.6682697036	.9	11	24.6	801.2	711	3
2021.5332523009	2.5133872175	.9	9	14.7	791.9	711	3
2021.5371458193	2.5126123354	.9	10	14.6	791.9	711	0
2021.5429991179	2.5104074706	.9	8	14.4	791.9	711	2
2021.6618402869	2.5081830400	.9	10	14.8	793.2	711	3
2021.6726909813	2.5084676332	.8	12	15.2	793.2	711	0
2021.6870023237	2.5078128616	1.0	6	15.9	793.2	711	2
2021.7371562591	2.5147811095	.9	10	20.3	793.2	711	3
2021.7435625091	2.5153420571	.9	10	21.3	793.2	711	0
2021.7566635190	2.5154875936	.9	11	23.4	793.2	711	2
2023.5709340461	2.4292964066	.9	10	15.0	802.6	711	3

2023.6877500183	2.4193170901	.9	10	13.0	802.6	711	3
2023.6921562683	2.4190166035	.9	10	13.1	802.6	711	0
2023.6952291850	2.4176256333	.9	10	13.1	802.6	711	2
2023.7992361296	2.4256173780	.9	10	17.6	803.9	711	3
2024.6085648338	2.3912864022	.8	12	14.8	801.2	711	3
2024.6126146022	2.3904178339	.9	10	14.6	801.2	711	0
2024.6167361300	2.3887060081	.9	11	14.5	801.2	711	2
2024.7215688320	2.3820360945	.9	11	12.8	801.2	711	3
2024.7282986300	2.3817338730	.9	9	12.8	801.2	711	0
2024.7330839836	2.3805540771	.9	11	12.9	801.2	711	2
2024.8505772757	2.3902917078	.9	8	18.2	801.2	711	3
2024.8676302274	2.3923890665	.9	8	20.2	801.2	711	0
2026.6648804212	2.3496132047	.9	9	16.4	802.6	711	3
2026.7973047074	2.3387763306	.9	8	12.6	802.6	711	3
2026.8054166866	2.3385746544	.9	10	12.7	802.6	711	0
2026.8169907606	2.3381164049	.9	9	12.7	802.6	711	2
2026.9321762005	2.3489542641	.8	12	17.3	801.2	711	3
2027.8042140357	2.3377206874	.9	11	12.9	801.2	711	3
2027.8102534927	2.3373130114	.9	10	12.8	801.2	711	0
2027.8191088168	2.3368102854	.8	12	12.7	801.2	711	2
2027.9260286663	2.3423599593	.9	8	14.3	801.2	711	3
2028.7049052986	2.3642598131	.9	9	22.6	798.6	711	3
2028.8229051136	2.3503905058	.8	12	13.5	799.9	711	3
2028.8346771044	2.3496269915	.9	10	13.2	799.9	711	0
2028.8437777641	2.3493248261	.9	8	13.1	799.9	711	2
2029.7992621742	2.3791707999	.9	8	16.9	795.9	711	3
2029.8096875213	2.3777923174	1.0	7	16.2	795.9	711	0
2029.9404375214	2.3738603113	.9	10	13.1	794.6	711	3
2029.9476128686	2.3744051077	.9	8	13.2	794.6	711	2
2030.9507143274	2.4055201910	.9	10	13.5	793.2	711	3
2030.9543460869	2.4054815008	1.0	6	13.5	793.2	711	0

2031.8394155323	2.4529426617	.8	12	23.3	795.9	711	3
2031.9715538419	2.4431827746	.9	8	14.2	797.2	711	3
2032.0967515661	2.4546496374	.9	9	17.4	797.2	711	3
2032.9548649807	2.4842888596	.9	9	16.5	803.9	711	3
2033.0956867401	2.4894204361	.9	9	16.5	802.6	711	3
2033.1694704976	2.5021446613	.9	8	24.0	803.9	711	3
2035.0071142101	2.5611107669	.9	9	20.2	791.9	711	2
2035.0785894223	2.5589446171	.9	8	17.3	789.2	711	2
2037.0691281000	2.6200956824	.9	9	24.3	801.2	711	3
2037.0791666802	2.6196776555	.9	9	23.3	801.2	711	2
2046.5521643538	2.6293345270	1.2	3	19.4	793.2	711	3

Table III. Summary of observations by reflector for 1973.

Reflector	Number
0	75
2	82
3	277
4	9

Table IV. Normal points for Lunakhod 2 observations during January -
February 1973. Headings are identical to those in Table II.

T*(UTC) 2440000+	Δ * TAI sec	ϵ * nsec	N	R nsec	P mbar	Obs code	Refl code
1707.9152365452	2.6235602508	1.1	16	22.2	793.2	711	4
1707.9971527782	2.6205233804	1.4	4	18.2	793.2	711	4
1723.6781423985	2.4461745046	1.4	4	21.1	797.2	711	4
1737.9985243325	2.6582808064	1.2	10	22.0	793.2	711	4
1738.0318364468	2.6585960759	1.2	9	22.0	793.2	711	4
1738.0705555826	2.6606775785	1.3	7	23.7	793.2	711	4
1738.1404514160	2.6687192987	1.3	5	35.5	797.2	711	4
1739.1150595501	2.6663923816	1.3	7	25.5	798.6	711	4

FIGURE CAPTIONS

Figure 1. Histograms of the 1969-1973 observation distributions with respect to the phase of each of the fundamental arguments of the lunar orbit motion. The sampling interval is 20° . The shaded portion represents the 1969-1972 data presented in Paper I and Paper II.

Figure 2. Histograms of the 1969-1973 observation distributions with respect to the lunar declination and the local hour angle of the moon. The sampling interval is 5° . The shaded portion represents the 1969-1972 data explicitly.



