REPORT ON THE LUNAR RANGING at MCDONALD OBSERVATORY FOR THE PERIOD MAY 16, 1972 TO SEPTEMBER 9, 1972*

by

E. C. SILVERBERG

and

F. W. HUDSON

UNIVERSITY OF TEXAS

Research Memorandum in Astronomy #72-010

September 1972

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Errata

page 16, para. 2, line 2

function, suggested by C. W. Clenshaw and supplied by John Rayner of......

page 18, para. 1, lines 7, 8, 9

are added. The sum is then made available as the approximate time of flight which has an RMS error of less than 2 nanoseconds. The time for the calculation is less than 22 milliseconds.

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ABSTRACT

About 115 lunar range measurements were obtained during the four lunations between 16 May and 9 September, 1972. Poorer than average weather conditions greatly affected the entire system operation. Changes in the method of creating lunar range predictions and an attempt to improve old calibration data were two of the few departures from relatively routine operation.

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I. SUMMARY OF THE QUARTER

Ranging - This quarterly report covers the four lunations ending on new moon, September 9th, 1972. During this period the lunar ranging project successfully obtained about 116 lunar range measurements. This data rate is only about one-half that of the previous three lunations during which 158 ranges were measured. The success rate, however, i.e. the number of measurements per attempt, was only slightly lower than before at 75%. Throughout the period the high accuracy feedback calibration system remained operational, thus permitting nanosecond accuracy on most of the measurements. No major changes in equipment occurred during the quarter, permitting relatively routine system maintenance on system hardware. As usual a log covering the daily operations is included as Appendix I.

The low acquisition rate during the last four lunations can be traced directly to the poor atmospheric conditions since May. As has been the case for some time, only about 10% of the lost laser data is a result of equipment failures. McDonald Observatory received approximately 12 inches of precipitation between May and 1 September, 1972. This was some 50% greater than average, and more than twice that received during the previous summer. In addition to closing down operations during the rainy periods, the humidity-related, convective cumulus nearly stopped all operations till one hour after sunset, even during the relatively dry days. Thus, we only used 80 out of some 200 scheduled operating periods during the previous four lunations.

In addition to the problems of clouds, the rather insidious effects of high water vapor absorption near the ruby laser wavelengths further affected our operations during the summer. The previous long drought at McDonald had dimmed memories regarding H_2O absorption and the laser had been allowed to shift appreciably in wavelength with no disasterous effects. The sudden onset of heavy rains, coupled with a misadjustment of the laser oscillator cavity, lowered the transmission and caused us to miss 11 out of 13 successive laser runs. Considerable time was required to locate and cure the cause of this difficulty. Some quantitative measurements on the seriousness of the water vapor problem are the subject of Section III A.

R & D - During the quarter the only significant change in the operation regards a method of getting the predicted range data. Beginning on 1 August we began calculating the predicted ranges in the Varian computer rather than reading them from JPL produced magnetic tapes. This not only makes the telescope operation much more effective, but is a great savings in nuisance value at both McDonald and JPL. A brief description of the calculating method is included as Section III B.

Following this introduction the quarterly report will document, as usual, the anomalies in system operation that might be significant to any possible postfacto data analysis. Most of this documentation concerns a rather fickle clock keeping system for a few weeks of the June and July lunations. Of additional interest, however, is an attempt to further improve our old calibration constants by comparing the present and past calibration systems. In doing so, some surprising insights emerged regarding our system stability.

Miscellaneous - No major personnel changes have occurred in the lunar ranging crew for some time. This leaves Silverberg, Wiant, Williams, Gonzales, and Baughn directly concerned with the daily documentation, maintenance and operation of the lunar ranging system. In addition the laser project now directly occupies a major fraction of the efforts of F. Hudson, a scientific programmer, to help with items such as Varian programming and the new 107" pointing procedures.

During the last quarter the project scientist traveled to Boulder, Colorado to attend a LURE Team quarterly meeting; and to Washington, D. C. to discuss a transportable laser station with NOA personnel.

II. DATA REDUCTION NOTES

A) Ammendments of Recent Data

Clock keeping - Due to frequent electrical storms it was not possible to keep the Loran C receiver consistently locked onto the same wave throughout the summer months. The phase skipping of the receiver, as well as numerous complete unlockings, made it most difficult to retain good accuracy on the preliminary clock data throughout this quarter. These problems were further enhanced by the redefinition of UTC on 1 July, requiring that the June-July clock cards be produced from an exceptionally short stretch of Loran C data. As a result, the preliminary data cards contained frequency readings which were no better than 6-12 parts in 10^{11} and epoch readings which erred by as much as 60 microseconds. As more clock data became available in successive weeks, such that the aging of the crystal became more apparent, it was possible to reprocess the timings with clock information which appears good to approximately 3 parts in 10^{11} and $\pm$ 30 microseconds respectively.

The redefinition of UTC on 1 July was not without some difficulty to the McDonald laser experiment. As near as we can reconstruct, the persons putting the final settings on the corrected clock on 1 July accidently hit the increment seconds button and thus undid the clock change which they had so carefully negotiated. Later that night a second error caused the mounting of prediction tapes which were written on the old UTC standard. Thus, even though the clock was operating one second fast, the crew still was able to acquire some data. The clock error was discovered the next day and corrected before the laser runs on 2 July.

As has sometimes been the case in the past, the time of day clock experienced a 1 millisecond positive epoch jump on 14 July. Since the discontinuity occurred during the new moon break this did not cause us any serious difficulties with our data reduction. The resulting discontinuity in the Loran C readings, however, further complicated the difficulty of producing good preliminary frequency and epoch calculations on the initial data cards.

Timing Problems - During the May-June lunation some evidence was seen for both a 50 and 120 nanosecond timing error on a small percentage of the data. These difficulties were both traced to an erroneous setting of the delayed clock (See Steggerda, 1970). It appeared that approximately 10% of the data was effected by either a 50 or 120 nanosecond error during the worst periods of this maladjustment. This could conceivably cause a false recognition of some data points during that and possibly one or two previous lunations before the system was readjusted. This note is to serve ample warning so that any such errors can be filtered out as early as possible.

Due to an apparent drift in the A to D conversion constants it was necessary to apply new vernier constants to the range conversion program on June 9th of this quarter. The cause of the drift is presently unknown. More is said about the system stability in Section III B, under the discussion of the calibration recovery.

B) Old Calibration Constants

The successful installation of the galium arsenide photomultiplier tube,as well as the operation of the feedback calibration system,has allowed stabilizing the lunar ranging electronics during the previous quarter. This permitted the use of certain consistency tests which were not possible until very recently. It also gave us an opportunity to recover information on the old calibration system which was used prior to 1 December, 1971. During the quarter feedback calibrations were performed as usual with particular care taken to only change components when it was absolutely necessary. In addition, a calibration constant was derived using the nanosecond light pulser as described in References 2 and 3. A sample of some of these tests is shown in Figure 1. Plotted are the uncorrected feedback calibration constants taken over the period, as well as calibration constants derived with the light pulser in the manner of February, 1970 to August, 1971. The two calibration numbers have been processed such that the pulser calibration should be 1 nanosecond higher than the feedback calibration. The bars on the feedback calibration represent formal statistical errors such as published on the monthly data cards.

The first note to mention with regard to Figure 1 is variability of the calibration constant over periods of only a few weeks. Systematic trends in the system performance as indicated by several successive measurements can leave no doubt as to wander of the system electronic delays. The cause of these variations is presently unknown; though daily temperature and line voltage records are now being kept. Clearly the need for day to day calibration is indisputable; at least until we find some method by which the system can be stabilized. A numerical analysis of three months of data indicates that the processed pulser calibrations average 0.1 nanoseconds lower than the feedback measurements, with an RMS deviation from the mean of 0.79 nanoseconds. The observed deviation from the mean is in complete agreement with the statistical errors expected from the feedback and pulser measurements of 300-400 and 500-700 picoseconds respectively. The indicated error in the pulser calibration method is far less than the statistical uncertainty of the test.

The previous test seems to be even further evidence that good calibration accuracy was maintained even before the feedback calibration came into use. If nothing else, there is no reason to suspect a systematic offset during the February 1970 - August 1971 period. Unfortunately, the test also points out a serious limitation of the early calibration data. Each of the previous calibration numbers was the average of several pulser measurements, sometimes taken over a period of as much as several weeks. It now appears that weekly deviations in the system performance will be the limiting factor in recovering the old data to higher accuracy.

In summary, we feel the following statements to be true. The calibration data derived from February 1970 to August 1971 by means of the light pulser will probably describe the calibration constant to be applied to any particular ranging effort with an accuracy of about $\pm$ 1.5 nanoseconds. On the other hand, that

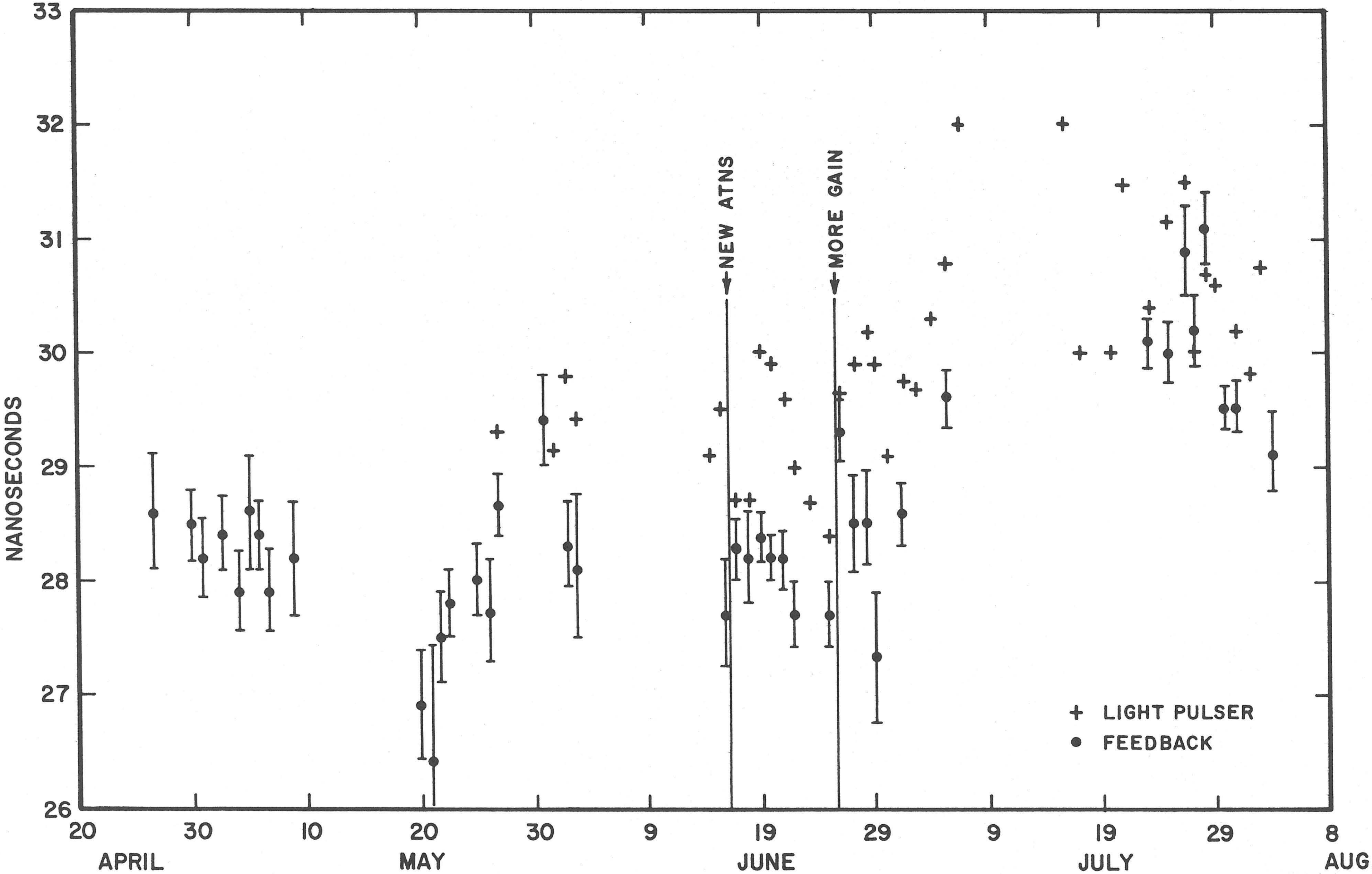

FIGURE: I CALIBRATION DATA: PULSER/FEEDBACK COMPARISON data will probably describe the <u>average</u> calibration constant which should be applied to one or two months of data with an accuracy of $\pm$ 0.5 nanoseconds. The total calibration constants, as derived by the light pulser, are shown on the next page.

CALIBRATION CONSTANTS

Feb. 4, 1970 (34)	to	May 8, 1970 (93)	161.3
May 9, 1970 (94)	to	Aug. 15, 1970 (227)	162.0
Aug. 15, 1970 (227)	to	Aug. 22, 1970 (234)	140.7
Sept. 10, 1970 (253)	to	Oct. 9, 1970 (283)	162.0
Oct. 10, 1970 (284)	to	Oct. 18, 1970 (291)	140.0
Oct. 19, 1970 (292)	to	Nov. 9, 1970 (312)	162.0
Nov. 10, 1970 (313)	to	Feb. 9, 1971 (40)	140.0
Feb. 10, 1971 (41)	to	March 3, 1971 (62)	130.0
March 4, 1971 (63)	to	April 19, 1971 (104)	130.4
April 20, 1971 (105)	to	May 23, 1971 (140)	135.9
May 24, 1971 (141)	to	June 1, 1971 (152)	131.5
June 2, 1971 (153)	to	July 3, 1971 (184)	131.4
July 4, 1971 (185)	to	July 5, 1971 (186)	130.6
July 6, 1971 (187)			130.5
July 7, 1971 (188)	to	July 27, 1971 (208)	129.9
July 28, 1971 (209)	to	July 29, 1971 (210)	130.3
July 30, 1971 (211)			147.8
Aug. 3, 1971 (215)	to	Aug. 5, 1971 (217)	131.1
Aug. 6, 1971 (218)	to	Aug. 30, 1971 (242)	131.3

III. SYSTEM R & D

A) Water Vapor Studies

As was mentioned in a earlier section, the optical efficiency was considerably lowered by heavy water vapor absorption at or near the ruby laser wavelengths. This was apparent both in the stellar calibrations taken during the summer, as well as in the returned signal from the lunar corner reflectors. Unfortunately, the cause of the lower efficiency was not realized immediately and several days were lost as the crew attempted to locate the problem in some 107" telescope component. Eventually it did become apparent that the optical components were operating no worse than par and that the 107" telescope efficiency was at its usual value of approximately 38%. This left us to conclude that the water vapor absorption was the cause of our difficulties. The results of the subsequent study are briefly given in the following few paragraphs.

On the next page, Figure 2, we show two spectra of scattered sunlight which were taken at McDonald Observatory. The ruby laser emission features are superimposed upon the same photograph. Blue wavelengths are to the right and the approximate dispersion, as printed, is equal to 0.15 angstroms per millimeter. The upper spectra was taken during the summer of 1971 under unknown humidity conditions. As you can see, the laser was transmitting in two emission lines separated by approximately .4 angstroms. Both of these lines were located rather conveniently between the water vapor absorption and indicated that we should have no difficulties with the ruby laser transmission in this region. Similar conclusions have been drawn by other investigators from data such as

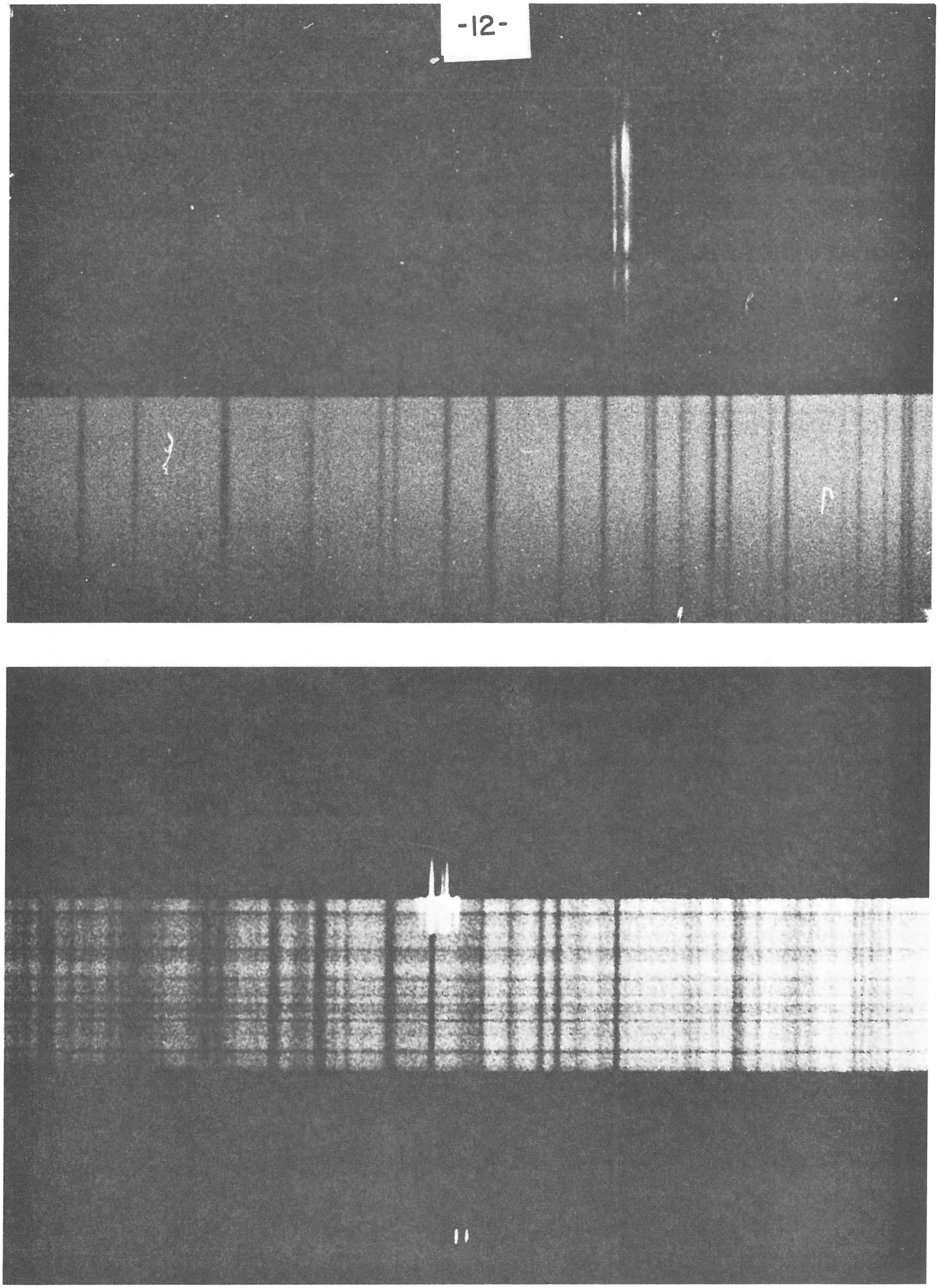

FIGURE 2 : LASER AND ATMOSPHERIC SPECTRA TAKEN IN JUNE, 1971 AND JULY, 1972.

these (See References 4 and 5).

The second spectrogram was taken in the summer of 1972 with the sun located near the zenith and approximately 8 millimeters of precipitable water along the light path. Two things differ from the spectrum taken in 1971. First, the laser is now emitting in four lines which have a total separation of 1.2 angstroms. Secondly, the gap between the water vapor absorption lines is very nearly closed; and the cores of the water lines are very nearly saturated. The brightest of the ruby laser lines is located at 6943.2Å. Photoelectric scans of this region show that the main water vapor absorption line on the red side, 6943.8Å, has only about 15% transmission. The darkest line on the blue side, at 6942.15Å, has only approximately 30% transmission at the core. The conditions shown on the second photograph taken in the summer of 1972 permit a two-way transmission of no more than 35% at the zenith and considerably less at the high zenith distances encountered during the summertime lunar ranging. It is no wonder then that eleven out of thirteen runs resulted in no signal return in early July. It is also clear that selective water vapor absorption is more important than we previously believed in determining the efficiency of a lunar ranging operation. During periods of high precipitable water vapor, that is, greater than 9-10 millimeters, even a perfectly tuned ruby laser will only receive a total two-way transmission of approximately 45% for typical summertime zenith distances.

In order to negate the effects of the water vapor absorption

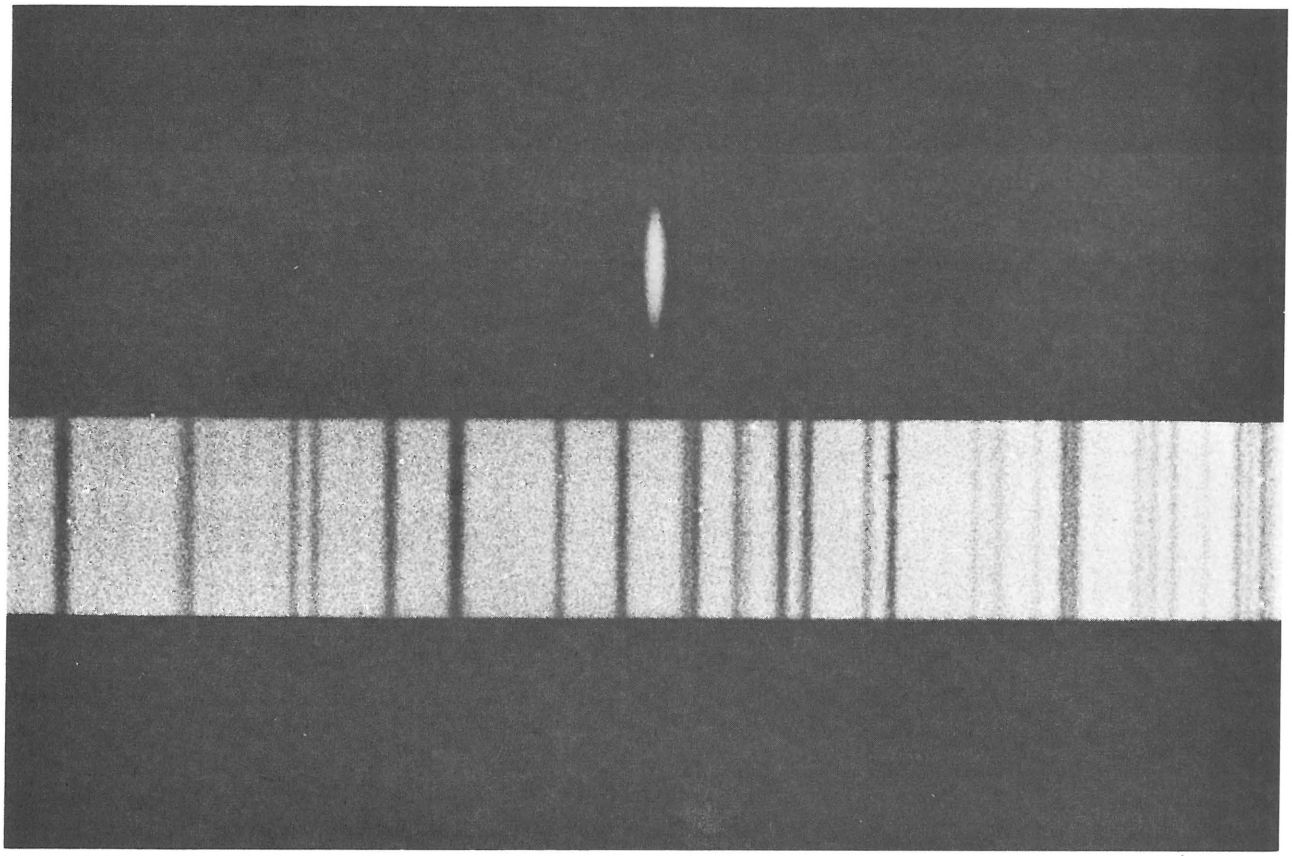

FIGURE 3 : LASER SPECTRUM TAKEN SEPT. 8, 1972 WITH NEW LONGITUDINAL MODE SELECTOR IN PLACE (3 SHOTS AT 3 JOULES, T = 64° F).

as much as possible, the laser was operated slightly higher in temperature and retuned as nearly as possible to single line operation. This resulted in operation almost identical to that shown in the first of the two spectra. That change permitted the regular acquisition of the lunar corner reflectors even though the signal still remained somewhat lower than we desired during periods of high water vapor content. Recently we were able to further improve on this performance by successfully installing a new Korad longitudinal mode selector. This cavity resonator forced single line operation at a wavelength of 6943.0Å and resulted in producing the spectrum shown in Figure 3.

B) Real Time Calculation of Predicted Ranges

Previous to 1 August, 1972 the predicted ranges were read from magnetic tapes after they were tediously calculated and stored and supplied by the Jet Propulsion Lab. With the addition of divide and multiply hardware and 8K words of core, the Varian 620/i computer was extended the capability of doing the calculation of those predicted ranges in real time. Thus, a complex of routines was written to concatenate data from coefficients supplied by a lunar ephemeris fitting routine to values usable as predicted ranges for any given time during a lunar day.

An algorithm for computing the Chebychev approximation of a function, suggested by C. W. Clemshaw and supply by John Rayner of the University of Maryland,

$$Y = \sum_{n=1}^{N} C_n T_n \ (X) \qquad -1 < x < 1$$

is, for nonarbitrary functions, to take

$$B_n = C_n$$

$$B_{n-1} = 2X * B_n + C_{n-1}$$

$$B_i = 2X * B_{c+1} - B_{c+2} + C_i$$

and finally

$$Y = X * B_2 - B_3 + C_1$$

where: C_i are coefficients supplied by the fitting routine; B_i are subsequent terms; X is the time mapped into the limits $-1 < X < 1$; and Y is the final function approximation. For the desired accuracy, an eleventh degree polynomial was used, since the maximum error is approximately equal to the magnitude of the largest coefficient which was dropped for T (N) < 1.

Since the Varian 620/i does not have a card reader, it was necessary to use the McDonald Observatory IBM 1800 computer to first produce a teletype readable paper tape. To perform the desired sequence, a preprocessing program, resident on the IBM 1800 disc, reads floating point coefficients and times from punched cards which are supplied by JPL. The program extracts the significant digits wanted (in the case of the first coefficient 2.2 seconds is subtracted, since this can be added in later without altering the calculation) and it scales each coefficient in increasing powers of two in order to retain significance. The program then formats nine significant digits for each coefficient into double precision, 30 bit, integer words and outputs these to paper tape. Along with the coefficients the values of the start time and stop time of the ranges are carried in a modified form for use in calculating the relative time of the time of flight. Each reflector used is supplied a different set of times and coefficients. Other identifying values are also punched on the paper tape.

The Varian 620/i may then read this paper tape and be ready to calculate ranges in real time. The operating system in the 620/i supplies the Chebychev routine the time of the laser firing and the number of the reflector to be ranged on. The routine initially does time checks and maps the time into the limits of

$$-2^{31} < X < 2^{31}$$

by normalizing and using triple precision routines and the start and stop time as boundaries. The main algorithm is executed and integer summation of the quadruple precision products is limited to the most significant two words, therefore reversing the normalization of X and utilizing the power of 2 scaling done in the preprocessing. The result is converted to a BCD representation in three 16 bit words and the 2.2 seconds, which were dropped before, are added. The sum is then made available as the approximate RMS error. The time for calculation is less than 22 microseconds.

A routine in the Varian 620/i system allows the authentification of predicted times of flight for any time span for which Chebychev coefficients are supplied. When the necessary coefficients are read, and appropriate teletype commands are given, 10 digit range predictions will appear for any requested epoch. These values may be compared to the ranges supplied by JPL.

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APPENDIX I

McDonald Lunar Ranging Operation Log

from

May 15, 1972 to September 5, 1972

STATION LOG, MAY-JUNE 1972

DATE	TIME	RUN NO.	NO. OF SHOTS	RETURNS	WEATHER	SEEING(π)	COMMENTS
May 17	15:30				cloudy		
	18:30				clear		painting dome
	21:30				"		preempted for super nova
May 18	16:15				cloudy		
	19:15				"		
	22:15				"		
May 19	17:00				cloudy		
	20:00				"		
	23:00				"		
May 20	17:45				cloudy		
	20:45				"		
	21:45	(258)	50/3	9/3	partly cloudy	3	
		(259)	200/0	6/0	"	3	
	22:45	(260)	70/3	10/3	"	3	
May 21	18:30				cloudy		
	20:35	(261)	100/3	11/3	light cirrus	3	
	00:15				cloudy		
May 22	19:15	(262)	150/3	9/3	clear	3	poor contrast
	21:00	(263)	100/3	16/3	clear	3	
		(264)	130/2	13/2	"	"	
		(265)	300/0	5/0	"	"	
		(266)	50/3	8/3	"	"	
	00:15	(267)	100/3	10/3	clear	3	
May 23	20:00	(268)	300/3	3/3	clear	4	very poor contrast
	23:00	(269)	100/3	11/3	clear	3	
		(270)	240/2	5/2	"	"	
		(271)	200/0	6/0	"	"	
		(272)	100/3	7/3	"	"	
	02:00	(273)	150/3	8/3	clear	3	
May 24	20:30	(274)	200/3	9/3	clear	3	
	23:40	(275)	300/3	7/3	clear	3	
		(276)	200/2	7/2	"	"	
		(277)	100/3	9/3	"	"	
	02:30				cloudy	3	
May 25	21:15				"		
	23:30	(278)	400/3	maybe 8	mod. cirrus	4	

DATE	TIME	RUN NO.	NO. OF SHOTS	RETURNS	WEATHER	SEEING(π)	COMMENTS
May 25	03:15				cloudy		
May 26	23:00	(279)	200/3	12/3	clear	2	
May 27	01:30	(280)	250/3	7/3	"	3	
		(281)	400/2	0/2	"	4	
		(282)	150/3	2/3	"	5	seeing progressively worse
May 28	00:00				cloudy		very heavy cirrus
	03:00				"		"
May 29	00:45				cloudy		heavy clouds
	04:30				'		seeing 5-7
May 30	01:30				cloudy		
	05:00				"		
June 1	03:00	(283)	350/3	6/3	mod. cirrus	3	110. a sco
	06:00	(284)	50/3	7/3	clear	"	
		(285)	300/0	6/0	"	"	
		(286)	230/2	0/2	"	"	
		(287)	175/3	8/3	"	"	
June 2	03:40				clear	2	laser electronic
	06:00	(288)	300/3	15/3	clear	2	trouble
		(289)	150/0	0/0	"	"	repaired electronic
		(290)	200/2	0/2	"	"	glitch causing 120
		(291)	150/3	4/3	"	"	nsec returns
June 3	05:00	(292)	250/3	5/3	partly cloudy	2	signal very poor
June 4	05:00				clear	3	worked on optics to cure low efficienc
June 5	06:00				cloudy		worked on optics to develop std. source
June 6	08:00				cloudy		

June 9 New Moon

Totals for May-June lunation

Tries	Successful Range Measurements
5/0	4/0
6/2	3/2
24/3	23/3

STATION LOG, JUNE-JULY 1972

DATE	TIME	RUN NO.	NO. OF SHOTS	RETURNS	WEATHER	SEEING(π)	COMMENTS
June 15	14:00				cloudy		cancelled
	17:00				"		"
	20:00-21:00	(293)	150/0	0/0	"	3	
June 16	15:00				cloudy		cancelled
	18:00				"		"
	20:00-22:30	(294)	400/0	0/0	clear	2	
June 17	16:00				cloudy		cancelled
	19:00				"		"
	22:00	(295)	200/0	0/0	clear	3	8.0mm H_2O
June 18	17:30-18:00	(296)	75/3	0/3	partly cloudy	3	stopped by clouds
	20:30-21:30	(297)	300/3	0/3	clear	3	
	23:00				cloudy		cancelled
June 19	18:00-18:35	(298)	200/3	0/3	clear	3	poor contrast
	21:00-21:35	(299)	400/3	0/3	clear	2	8.5mm H_2O
	00:15-00:45	(300)	150/3	0/3	clear	4	
June 20	19:00-19:30	(301)	100/3	0/3	clear	3	
	21:00-21:45	(302)	300/3	5/3	clear	3	7.5mm H_2O
	00:30-01:00						water vapor high
							run cancelled
June 21	21:00-21:45	(303)	250/3	4/3	clear	3	laser L.M.S. removed
	00:00-00:45	(304)	350/3	0/3	clear	3	
June 22	20:CC				partly cloudy		used for transmission
	00:00				"		tests
June 23	22:00				cloudy		cancelled
	01:30				"		"
June 24	23:00-00:00	(305)	300/3	0/3	partly cloudy	2	
June 26	00:00				partly cloudy		used for transmission
							tests
	03:00-04:15	(306)	200/3	16/3	"	2	good efficiency for
		(307)	370/0	maybe4/0	"		a change

DATE	TIME	RUN NO.	NO. OF SHOTS	RETURNS	WEATHER	SEEING(")	COMMENTS
June 27	01:00-01:55	(308)	50/3	11/3	clear	2	put back K.L.M.S.
		(309)	200/0	0/0	"	"	
		(310)	75/3	10/3	"	"	
	03:30-04:00	(311)	150/3	10/3	clear	3	
June 28	01:30-02:15	(312)	150/3	12/3	clear	3	
		(313)	50/3	9/3	"	"	
	04:00-04:15	(314)	100/3	10/3	clear	3	
June 29	02:00-02:45	(315)	50/3	10/3	clear	2	4mm H_2O
		(316)	150/0	8/0	"	"	
	03:45-04:30	(317)	100/3	10/3	clear	2	
		(318)	150/2	8/2	"	"	
	06:15-06:40	(319)	100/3	11/3	clear	3	
June 30	02:15				cloudy		cancelled
	05:15				"		"
	06:15-07:00	(320)	50/3	9/3	clear	4	
		(321)	150/0	3/0	"	"	stopped by clouds
July 1	03:00-03:30	(322)	125/3	0/3	cloudy	3	wrong ephemeris
	06:00				cloudy		cancelled
	08:00-09:30	(323)	80/3	13/3	partly cloudy	3	clock 1 sec. off
							old predict tapes
		(324)	150/0	10/0	"	3	"
		(325)	200/2	4/2	"	"	poor contrast
July 2	04:00				cloudy		cancelled
	06:30				"		"
	09:00				"		"
July 3	04:00				cloudy		cancelled TGD Down
	06:30				"		"
	09:00				"		"
July 4	05:00				cloudy		cancelled
	07:30				"		"
	09:30				"		"
July 5	05:30				cloudy		cancelled
	08:30						
	01:30						

DATE	TIME	RUN NO.	NO. OF SHOTS	RETURNS	WEATHER	SEEING (π)	COMMENTS
July 6	07:00-07:30	(326)	120/3	0/3	partly cluody	3	Stopped by clouds
	09:00-09:45	(327)	240/3	0/3	heavy cirrus	"	Computer off
							Encke C

July 7-14 New Moon

Totals for June-July lunation

Tries	Successful Range Measurements
8/0	3/0
0/1	0/1
2/2	2/2
25/3	14/3

STATION LOG, JULY-AUGUST 1972

DATE	TIME	RUN NO.	NO. OF SHOTS	RETURNS	WEATHER	SEEING(")	COMMENTS
July 15	15:05				Cloudy		Cancelled
	18:05				Cloudy		Cancelled
	21:05				Cloudy		Cancelled
July 16	15:47				Cloudy		Cancelled
	18:47				Cloudy		Cancelled
	21:47				Cloudy		Cancelled
July 17	17:35				Cloudy		Cancelled
	20:35				Cloudy		Cancelled
July 18	18:00				Cloudy		Cancelled
	21:00				Cloudy		Cancelled
July 19	18:00				Cloudy		Cancelled
	21:00				Cloudy		Cancelled
July 20	18:44				Cloudy		Cancelled
	21:44				Cloudy		Cancelled
July 21	21:00				Partly cloudy		Cancelled
	01:00				Cloudy		Cancelled
July 22	21:00				Partly cloudy		TDG trouble cancelled
	23:00-23:55	(328)	400/3	16/3	Partly cloudy	2	
July 23	21:00-21:30	(329)	250/3	10/3	Partly cloudy	2	
	01:30-02:30	(330)	200/3	9/3	clear	2	
		(331)	300/0	4/0	"	"	
		(332)	100/3	9/3	"	"	
July 24	23:30-00:00				Cloudy		TDG trouble cancelled
	03:00-04:00	(333)	100/3	9/3	Clear	2	
		(334)	300/0	6/0	"	"	
		(335)	100/3	9/3	"	"	
July 26	00:00-01:00	(336)	100/3	12/3	Clear	3	
		(337)	250/0	3/0	"	"	
	03:40-03:50	(338)	50/3	12/3	"	"	

DATE	TIME	RUN NO.	NO. OF SHOTS	RETURNS	WEATHER	SEEING(π)	COMMENTS
July 27	00:45-01:45	(339)	50/3	13/3	Clear	2	
		(340)	250/2	0/2	"	"	
		(341)	50/3	7/3	"	"	
	04:00-04:10	(342)	50/3	10/3	"	"	
July 28	01:00-02:00	(343)	90/3	18/3	Clear	2	
		(344)	100/2	10/2	"	"	
		(345)	150/0	8/0	"	"	
		(346)	50/3	9/3	"	"	
	07:00				Partly cloudy		Cancelled
July 29	01:15				Cloudy		Cancelled
	04:15				Cloudy		Cancelled
	07:15				Cloudy		Cancelled
July 30	02:10-02:40	(347)	150/3	9/3	Partly cloudy	3	moderate clouds
	05:00-06:00	(348)	50/3	12/3	" "	"	Using Tcheb. poly.
		(349)	150/0	11/0	" "	"	
		(350)	150/2	8/2	" "	"	
		(351)	50/3	10/3	" "	"	
	08:00-08:40	(352)	175/3	10/3	Clear	2	
July 31	02:45-03:20	(353)	200/3	0/3	Clear	2	Bad Cheb.
	06:15-07:15	(354)	75/3	10/3	Clear	2	Used Mag. Tape
		(355)	100/2	10/2	"	"	"
		(356)	150/0	0/0	"	"	Computer Godin a Used Cheb.
		(357)	70/3	10/3	"	"	Used Mag. Tape
	08:45-09:15	(358)	100/3	14/3	"	"	Used Cheb. Bad Contrast
		(359)	90/0	0/0	"	"	Computer guided
Aug. 1	03:52				Clear		TDG trouble
	06:52				"		"
	09:52				"		"

DATE	TIME	RUN NO.	NO. OF SHOTS	RETURNS	WEATHER	SEEING(π)	COMMENTS
Aug. 2	04:46				Cloudy		Cancelled
	07:46				Cloudy		Cancelled
	10:46				Cloudy		Cancelled
Aug. 3	06:30-07:15	(360)	275/2	6/2	Partly cloudy	4	
		(361)	90/3	0/3	" "	"	Stopped by clouds
	09:45-10:20	(362)	150/2	8/2	Clear	4	
		(363)	150/3	0/3	"	"	
Aug 4	06:43				Cloudy		Cancelled
	09:43				"		"
	12:43				"		"
Aug 5	07:45				Cloudy		Cancelled
	10:45				"		"
	13:45				"		"
Aug 6	08:46				Cloudy		Cancelled
	11:46				"		"
	14:46				"		"

Aug 7-11 New Moon

Totals for July-August lunation

Tries	Successful Range Measurements
7/0	5/0
0/1	0/1
6/2	5/2
23/3	20/3

STATION LOG, AUGUST-SEPT. 1972

DATE	TIME	RUN NO.	NO. OF SHOTS	RETURNS	WEATHER	SEEING	COMMENTS
Aug. 12	13:00				cloudy		run cancelled
	16:00				cloudy		run cancelled
	19:00				cloudy		run cancelled
Aug. 13	13:45				cloudy		run cancelled
	16:45				cloudy		run cancelled
	19:45				cloudy		run cancelled
Aug. 14	14:45				cloudy		run cancelled
	17:45				cloudy		run cancelled
	20:45				cloudy		run cancelled
Aug. 15	15:30				cloudy		run cancelled
	18:30				cloudy		run cancelled
	21:30				cloudy		run cancelled
Aug. 16	16:30				cloudy		run cancelled
	19:30				cloudy		run cancelled
	22:30	(364)	300/3	0/3	clear	4	
Aug. 17	17:00				cloudy		run cancelled
	19:00-20:30	(365)	130/3	12/3	clear	2	
		(366)	325/0	0/0	"	"	
		(367)	100/3	8/3	"	"	
	22:45-23:20	(368)	250/3	11/3	"	"	
Aug. 18	19:00-19:15	(369)	60/3	2/3?	ptly cldy	3	stopped by clouds
	23:00				cloudy		run cancelled
Aug. 19	19:45				cloudy		run cancelled
	23:00				cloudy		run cancelled
Aug. 20	20:45-21:45	(370)	60/3	12/3	clear	2	
		(371)	50/2	6/2	"	"	
		(372)	200/0	7/0	"	"	
		(373)	60/3	10/3	"	"	
	01:00-01:15	(374)	100/3	9/3	ptly cldy	2	
Aug. 21	23:30-00:30	(375)	100/3	8/3	ptly cldy	1	
		(376)	200/0	4/0	"	"	cirrus forming
		(377)	50/3	1/3	"	"	laser problems
	02:30				ptly cldy		laser down

DATE	TIME	RUN NO.	NO. OF SHOTS	RETURNS	WEATHER	SEEING	COMMENTS
Aug. 22	21:30				cloudy		run cancelled
	00:15	(378)	50/3	8/3	clear	3	
		(379)	150/2	0/2	"	"	
		(380)	150/3	7/3	"	"	
Aug. 22	03:30				cloudy		run cancelled
Aug. 23	22:40	(381)	180/3	10/3	clear	2	
	01:30-02:30	(382)	175/3	10/3	"	"	
		(383)	250/0	5/0	"	"	
		(384)	215/3	10/3	"	"	
	04:40				clear	6	bad seeing
Aug. 24	22:45	(385)	250/3	8/3	ptly cldy	3	
	02:00	(386)	135/3	10/3	"	"	
		(387)	60/0	0/0	ptly cldy	3	stopped by clouds
Aug. 25	01:30				cloudy		run cancelled
	05:00				cloudy		run cancelled
Aug. 27	02:00				cloudy		run cancelled
	06:00				cloudy		run cancelled
Aug. 28	02:30				cloudy		laser problems
	07:00-08:00	(388)	150/3	10/3	cirrus	2	
		(389)	160/2	0/2	"	"	
		(390)	150/0	0/0	"	"	
Aug. 29	02:30-03:00	(391)	40/3	10/3	cirrus	2	
	06:15:07:30	(392)	150/3	11/3	"	3	
		(393)	350/0	4/0	"	"	
		(394)	80/3	11/3	"	"	
Aug. 30	03:40-04:00	(395)	50/3	9/3	clear	2	
	06:00-07:45	(396)	50/3	9/3	"	2	
		(397)	140/2	10/2	"	"	
		(398)	270/0	3/0	"	"	
		(399)	80/3	21/3	"	"	
Aug. 31	04:00-04:20	(400)	50/3	11/3	clear	2	
	06:30-08:00	(401)	50/3	17/3	"	"	
		(402)	350/2	22/2	"	"	
		(403)	50/3	13/3	"	"	
		(404)	170/0	2/0?	"	"	

STATION LOG, AUGUST-SEPT. 1972

DATE	TIME	RUN NO.	NO. OF SHOTS	RETURNS	WEATHER	SEEING	COMMENTS
Sept. 1	06:00-08:00	(405)	180/2	10/2	ptly cldy	3	
		(406)	130/3	10/3	"	"	
		(407)	300/0	3/0	"	4	
		(408)	150/2	0/2	"	5	
Sept. 2	06:00				cloudy		run cancelled
Sept. 3	07:00				cloudy		run cancelled
Sept 4-9	New Moon						

TOTALS FOR AUGUST SEPT. LUNATION	TRIES	SUCCESSFUL RANGE MEASUREMENTS
	10/0	7/0
	0/1	0/1
	7/2	4/2
	28/3	26/3

TOTALS FOR THE QUARTER	TRIES	SUCCESSFUL RANGE MEASUREMENTS
	30/0	19/0
	0/1	0/1
	21/2	14/2
	100/3	83/3
	151	116

APPENDIX II

Calibration Data

for the

Lunar Ranging Electronics

KEY: (See Reference 4 for a more complete explanation)

A) Uncorrected calibration constants as derived by the auxiliary light emitting diode.

B) Uncorrected calibration data as measured by the auxiliary feedback calibration system using the pulse height analyzer.

C) Uncorrected feedback calibration data as printed out by the Varian computer during lunar ranging.

D) The corrected electronic calibration constant (in tenths of nanoseconds) as distributed on the monthly data cards.

Calibration Data (May-June)

Date	A	B	C	D
May 20, 31034A 2200V, G = 10, D = 190, RC = 5, F = 0.5		27.9	26.9C	
May 21			26.4E	235E
May 22		27.8	27.5B	246B
May 23		28.2	27.8B	249B
May 25		28.3	28.0B	251B
May 26		28.7	27.7C	258C
May 27	30.0		28.7B	258B
June 1			29.4B	265B
June 2		29.0	28.3B	254B
June 3	31.2	28.7	28.1D	252D

Calibration Data (June-July)

Date	A	B	C	D
June 14, 31034 Old parameters	30.7			
June 16, GMT Old parameters	31.1	27.7	27.7C	258C
June 17, GMT, New ATNS	30.3	28.3	28.3B	264B
June 18, GMT	30.3		28.2B	263B
June 19	30.0		28.4A	265A
June 20	29.9	29.9	28.2A	263A
June 21	31.2		28.2B	263B
June 22	30.6	29.8	27.7B	258B
June 24	30.3			258B
June 25	30.0	29.3	27.7B	258B
June 26 More gain, G = 20	31.2	30.4	29.3B	274B
June 27	31.5	30.3	28.5B	266B
June 28	31.8	29.7	28.5B	266B
June 29	31.5	30.8	27.4C	255C
June 30	30.7	30.6	26.6D	247D
July 1	31.4		28.6A	267A
July 3	31.3			
July 4	31.9			
July 6	32.4		29.6B	277B
July 7	33.6			

Calibration Data (July-August)

Date	A	B	C	D
July 16, G = 20, D = 190, V = 2200	33.6			
July 17 (199)	31.6			
July 22 (204)	31.7			
July 23 (205)	33.0		31.6?	272C
July 24 (206)	31.9		30.1A	272A
July 25 (207)	32.8	32.5	30.0A	271A
July 26 (208)	33.1	41?	30.9B	280B
July 27 (209)	31.6		30.2B	273B
July 28 (210)	32.3		31.1B	282B
July 29 (211)	32.2			
July 30 (212)			29.5A	266A
July 31 (213)	31.8		29.5B	266B
August 1 (214)	31.4			
August 2 (215)	32.3			
August 3 (216)			29.1B	262B

Calibration Data (August-September)

Date	A	B	C	D
August 14, 31034 at 2200, G = 20, D = 190	32.5			
August 15 (228)	33.5			
August 16 (229)	31.5			
August 17 (230)			29.8B	269B
August 18 (231)			29.5B	266B
August 21 (234)	31.2	30.5	29.4B	265B
August 22 (235)	30.9		29.6B	267B
August 23 (236)	32.5		29.6B	267B
August 24 (237)	33.3	30.7	29.5A	266A
August 25 (238)	33.3	30.6	29.9B	270B
August 26	31.4			
August 27	31.8			
August 28 (241)	31.6	30.8	29.5B	266B
August 29 (242)	32.3	30.6	29.5B	266B
August 30 (243)	31.5		30.0B	271B
August 31 (244)	32.3	30.5	29.7A	268A
September 1 (245)	31.5	31.6	29.8B	269B