ANNUAL REPORT

(December 1, 1964 to November 30, 1965)

GRANT NsG 56-60

From

THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

To

THE CALIFORNIA INSTITUTE OF TECHNOLOGY

By

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Pasadena, California

CONTENTS

Change in Reporting Procedure

In accordance with discussions with Mr. Robert Bryson of NASA headquarters, we are modifying our reporting procedure so that the Annual Report will be prepared in March of each year, and a semi-annual report will be submitted concurrently with the proposal for the new grant year, i.e., in September.

1. INTRODUCTION

This is a report of research activities carried out during the sixth year of grant NsG 56-60, which ended November 30, 1965, from the National Aeronautics and Space Administration to the California Institute of Technology. Also included is a summary report of our work during the first three months of the present grant year, i.e., through March 30, 1966.

Our research is summarized in Section 2. Publications are listed separately at the end of this report. The graduate student program is outlined in Section 3. Relationship to the Space Program is discussed in Section 4 and a financial summary is presented in Section 5.

The permanent research staff remained more or less unchanged during the sixth grant year. Mr. James Westphal was promoted to Senior Research fellow in the Division of Geological Sciences, a staff appointment in recognition of his increased and effective scientific participation. Formerly he was a Senior Engineer. During the first half of the present grant year a temporary employee, Barbara Schwartz, left to return to graduate work, and a second part-time employee, Carolyn Prunty, left to join the Peace Corps and was replaced by Lily Ray.

2. SUMMARY OF RESEARCH

Our research supported by NsG 56-60 continues to be directed in three principle areas:

1) Characteristics of planets, meteorites and asteroids, particularly regarding orbital distribution and chemistry, which may afford clues as to the origin and evolution of those objects as well as to the Solar System as a whole.

2) Ground-based physical observations of the Moon and Planets, and related interpretations, in the visible and long-wavelength infrared.

3) Laboratory investigations of the thermal radiative properties of powders in vacuum, with applications to the interpretation of lunar infrared observations.

As has been emphasized in previous reports, meteorites provide our most likely illustrations of the range of chemical compositions to be expected in the asteroids, in the Moon and in the planets. There are at least 25 distinct chemical families of meteorites. The relationships between these families can provide valuable clues which may eventually enable us to understand the chemical evolution of our solar system and to forecast the kinds and relative proportions of chemical substances to be expected in Class I* planets and satellites. Further there appears to be a small yet finite chance that although most meteorites have their origin in the asteroid belt, some might be fragments of the lunar surface, knocked off by the impact of large meteorites. In view of this possibility, it is important that we attempt to identify which, if any, of these 25 or so families might be of lunar origin.

Largely as a result of such considerations, a systematic program has been undertaken for several years aimed at producing data on the chemical composition of meteorites in the quantity and of the quality necessary for sound statistical analysis.

The determination by x-ray fluorescence of the composition of 84 stony meteorites including ten representatives of the brecciated chondrites and achondrites, have been completed and the results obtained are now being prepared for publication. Charts and tables presenting the results are shown in the separate Appendix.

Briefly the basic division of chondrites into "low-iron" and "high-iron" groups (Urey and Craig, 1953) has been confirmed. Other groups, namely the low- and high-nickel groups and the low- and high-cobalt groups are observed also.

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* The term "Class I" refers to objects composed almost entirely of metallic elements and oxides.

Nine of the ten brecciated chondrites examined were found to fall either into the high or the low groups. The chondrite Plainview provides a notable exception to this generalization.

Possible correlations between the observed iron, nickel and cobalt groups, the mineralogical composition of the meteorites, the concentrations of selected trace elements and other measurable properties such as the cosmic-ray exposure ages and time of fall are now being investigated.

The concentrations of copper and vanadium have been determined by emission spectrography for all stony meteorites which have been investigated by x-ray fluorescence. It has been discovered that on a volatile-free basis, the carbonaceous chondrites are more variable than the high and low-iron (nickel and cobalt) group chondrites and generally have higher concentrations of copper and vanadium. The ratio of copper to vanadium is highest (4.8) in the carbonaceous chondrite Orgueil and lowest (0.07) in the hypersthene achondrite Shalka. The results are also shown in the separate Appendix. A detailed account of the work will be published soon.

As has been mentioned in earlier reports, the elements of all numbered asteroids were punched on IBM data cards for the purpose of studying groupings and other regularities among the elements. An IBM 7090 computer was used to calculate secular elements such as the proper eccentricity and the proper inclination. All possible combinations of the orbital elements were then plotted using the General Dynamics' High Speed Microfilm Recorder S-C 4020.

Many hundreds of plots of asteroid elements were obtained as a result of this work. From these a group of 44 has been selected for publication in permanent form. Taken as a group these plots, presented in Appendix I, show the more significant relationships between the elements.

These plots have been analyzed in considerable detail and the results of those analyses are now being prepared for publication. They bring out clearly the existence of the "families" described by Hirayama and later by Brouwer, together with indications of the existence of families as yet unreported.

An analysis is now underway of the distribution of the absolute magnitudes of asteroids in relation to orbit and family grouping. The absolute magnitude is a function of asteroid size and albedo. The albedo in turn must be a function of the chemical composition together with such variables as thermal history, radiation exposure history and general surface characteristics.

The study thus far indicates that families of asteroids might differ markedly from each other in the distribution of their absolute magnitudes.

In a preliminary paper published about 18 months ago* it was pointed out that planetary systems might well be extremely abundant in our galaxy. The conclusions were based upon: 1. An analysis of the chemical characteristics of planets relative to the chemical composition of the sun, 2. An analysis of the distribution of stars with respect to size, 3. An analysis of the relative abundances of multiple star systems, including known invisible stellar components.

The analysis is now being prepared for publication in more complete form in three parts under the general title "Relationships Between Stars and Planets".

A major step forward in our telescope observational programs was made possible by the relocation of our 24" telescope from White Mountain California, onto the grounds of the Mt. Wilson Observatory. An excellent dome and related facilities, originally used to house the 10" Astrograph, has been made available to us without charge by the Mt. Wilson Observatory. Accordingly, the considerable logistic difficulties which are inherent in operations at White Mountain have been overcome. We are already experiencing an accelleration of effort and anticipate more. Some of these programs are described in Section 3. In addition Jim Westphal** was able to carry out exciting and most important observations of the comet 1965f throughout the infrared, the first time such measurements have been made. Also the integral brightness of Mercury in the 8-14μ region has been observed within 8° of the sun, closer than ever before and of considerable significance to the question of the nighttime temperature of the planet.

The 60" and Snow telescope programs are also described in Section 3.

The 200" was again used to improve knowledge of Venus, this time by Westphal to obtain the highest resolution limb-darkening profiles of the planet at 9, 11, and 13μ. Murray continued his program of observing the dark side of Mercury directly in the 8-14μ region, and various other continuing programs were carried out.

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*Harrison Brown "Planetary Systems Associated with Main Sequence Stars". Science 145 pp. 1177-1181 (1964).

** In conjunction with Eric Becklin, a graduate student in the Physics Department.

3. GRADUATE STUDENT PROGRAM

Our graduate student program again continues to gain momentum both in numbers and in the diversity of student research. Three new graduate student's appear to have chosen Planetary Science as their field of specialization (Chadwick, Cutts, Werner). Four advanced students are in various stages of research specialization (Goetz, Kieffer, McCord, Matson). Also, two other students, (Roddy, McGetchin), not supported under Grant NsG 56-60, are completing Ph.D thesis on terrestrial geological structures of valuable importance to Lunar Geology. This work is mainly under the guidance of Dr. Eugene Shoemaker. Finally several other graduate students not specializing in Planetary Science have done minor research projects on impact craters as part of their oral examination.

During 1965, Alexander Goetz, Jr. continued his Ph.D Thesis investigation of the emissive properties of silicate powders in the 8-14 micron region. Emphasis has been placed on doing a thorough study of the special properties of a select group of rock and mineral powders as a function of grain size and surface temperature under vacuum conditions. Previous workers in the field have found the spectral contrast of very fine powders in air and at temperatures of about 250 deg C to be vanishingly small. Some preliminary evidence from the current program points to the fact that under high thermal gradient conditions (100° c/mm) substantial departures from grey body emission are present in very fine powders. Thin sections (50 microns and less) of different minerals are now being prepared for IR absorption measurements. These data will aid in computing a theoretical model of the behavior of small particles under high thermal gradient conditions.

During the year a digital voltmeter - paper punch combination were added to facilitate data reduction. Each spectrum is digitized in real time and consists of about 900 points covering the 8 - 14 micron region. Digitization allows the data to be reduced entirely in the computer. In the laboratory data reduction the end result of each series of measurements is a computer plot. Fig. 1 is such a plot which contains the emission spectrum of the powder, the Planck curve which most nearly approaches the radiation temperature of the powder surface and another Planck curve five degrees higher in temperature.

A second plot shows the relative emissivity which is merely the Planck curve divided by the sample emission. The relative emissivity is by no means the true emissivity but does give a measure of spectral contrast.

This year the IR spectrometer used in the laboratory work was successfully mated to the existing photometer, and a lunar observational program on the 24 inch telescope was initiated. A series of tests on atmospheric transmission stability has been made which show that,under favorable conditions, average fluctuations over a 15 minute interval amount to less than two percent. A series of differential measurements of the 8 - 14 micron lunar emission has been made. The wave length resolution is approximately .07 microns and the spatial resolution is approximately 20 miles at the sub-earth point.

In the months of December through March a total of only six nights were favorable during the bright run. This was close to the actual number of clear nights.

Both laboratory and telescope observations should be completed during the fall of 1966. Differential spectra of a number of points of interest on the moon will be taken. These will be correlated with previous laboratory measurements to place limits on the particle size and possible the compositional differences across the lunar surface.

Mr. Hugh Kieffer took leave from his activities at C.I.T. in order to spend four months in Antartica where he participated in several significant research programs. He also completed a theoretical analysis of planetary interiors which is currently being prepared for publication.

In that study theoretical studies were undertaken to determine the physical characteristics of families of simple model planets composed of the more abundant elements and chemicals and to study the effects of different modes of layering and mixing these substances within the planet.

The substances considered are those thought most likely to occur in planets, i.e. H, He, CH_4, NH_3, H_2O, and a silicate-metal mixture. The equations of state thought most reliable were selected from the literature, though a theoretical extension of the equation of state to higher pressures was necessary in all cases.

A flexible computer program was developed which will handle variable mass abundance ratio, layering sequences, phase changes, and will automatically preform any iterations necessary to match input boundary and total mass conditions. The mathmatical treatment is analogous to physically realizable bodies so that a small residual core of very high density material is not required, as has been in much of the published work. A first order approximation of rotational effects is optional. An analysis of error and approximations has been made. Logrithmic interpolation of

the equation of state was determined to be physically more realistic than liner interpolation and was used throughout the computations. Values of pressure, density, gravity, and the interior mass, inertia, and coefficient of inertia (I/MR^2) were printed out at frequent interval of radius and at all layer boundries.

Models of planets composed of each of the six substances were computed over a wide range of mass (10^{25} to LO^{31} grams). Models of the Class II and Class III planets of Brown (1964) were computed for the cases of complete layering, geochemically likely layering, and complete mixing. The simple system of pure hydrogen-helium models (cold) was studied in some detail to determine the effect of layering for different mass abundance ratios.

Initial analysis shows that two indicies of compression, (the decrease in inertia and increase in central pressure relative to a constant density body of the same mass and radius), bear a nearly constant relation to each other. An approximate analytical expression for the mass-radius curves of the single substance models is being studied.

An unexpected result is that the single substance models of both helium and methane can have nearly the same mass and radius as Neptune, though this is not taken to suggest that Neptune is either nearly pure helium or pure methane.

The mass-radius curve of the Class III models passed close to the plot of Jupiter, and a set of appropriate Jovian models were computed incorporating a first order approximation for the proper rotation velocity.

Thomas McCord continued the search for lunar luminescence with the 60 inch telescope and achieved a sensitivity greater than ever before achieved anywhere. Reports of the lunar surface luminescening have been made with increasing frequency during the last 15 years although very little data have been published. In the present survey a systematic search for lunar luminescence was made using the line depth method and a photoelectric detection system. Observations were made of 25 different lunar positions over 6 lunation cycles during 1965. No differential luminescence has been found on the lunar surface that exceeds 2 per cent of solar continuum in the spectral region of the Ca^{II} H and K lines. However, small but statistically meaningful differences in behavior are found for different lunar positions and for different observation times. It seems increasingly likely that lunar luminescence on the 5%-10% scale is quite rare. These results will be published during the present year.

Mr. McCord also initiated his Ph.D thesis investigation of lunar colormetry. The existance of differences in color with position on the lunar surface has been reported by several workers. Unfortunately most work in this area has been done using photographic techniques, which are subject to systematic error. Because of the nature of the response function of a photographic emulsion, albedo contrasts tend to appear as color differences. Also the variations in the response of different plates with wavelength and exposure times could distort the true color differences that may exist on the lunar surface.

The varification of the existance of color differences on the lunar surface is an important problem because of the possible relation of composition and/or age to color. Indeed, it may be possible to map lunar compositional provinces from Earth-based telescopes.

Therefore a program has been undertaken to design, build and use a precision photoelectric, double-beam colorimeter to attack the above stated problem. The instrument will have the capacity to compare two selenographic areas simultaneously in one narrow wavelength region of the spectrum to better than 0.01 magnitudes. The entire visible spectrum from 4000 Å to 8500 Å will be studied using 21 individual filters. The instrument is presently under construction and will be in operation this summer.

Mr. McCord also completed his study of the effect of Tidal Friction on the History and Lifetime of Triton. In this study, the effect that frictionally retarded tides may have on the Neptune-Triton system has been investigated for time past, present, and future. This was done by deriving the disturbing potential due to laging tides on Neptune and Triton and using it in Gauss's equations for the time rate of change of Triton's orbit. It is found that Triton could have existed in the past in an extended and highly eccentric orbit suggesting that Triton was not always a satellite of Neptune. At least interaction has occurred between Triton and Neried. Currently Triton's orbit may be changing by a measurable amount. Detection of this change would give information about Neptune and the history of the system. In the future Triton is found to crash onto Neptune in times short on a solar system time scale even when very small tidal phase lags are considered. These results will also be submitted for publication soon.

Mr. Dennis Matson has emphasized planetary spectroscopy during the past year. The pit spectrograph of the Snow Telescope on Mt. Wilson was utilized by him and Murray and McCord for observations of Ikeya-Seki (1965f) on October 20 and 21, 1965. Dispersion at 3900 Å was 3.5 Å/mm. Several difficulties inherent in the Snow Telescope made observation.

of the comet tedious and reduction of the data difficult. The spectra we obtained show about a dozen metallic emission lines. Most significant they record a peculiar splitting of the sodium D lines.

On November 6, 1965, McCord and Matson again observed Ikeya-Seki while they were working at the Cassegrain focus of the Mt. Wilson 60-inch reflector. Observing visually at 0521 PST, they found the comet to consist of two pieces aligned along the axis of the comet and separated by about 10 seconds of arc. Unfortunately attempts to obtain spectra on this morning were not successful.

Matson also carried out a program of investigation of the luminescence of the earth's atmosphere in connection with the search for lunar luminescence. Results of the study show that when the solar spectrum is compared with the spectrum of scattered light in the atmosphere, the cores of the K, H and H Fraunhofer lines are enhanced by 4.3%, 5.4% and 19.8% with respect to nearby continuum. At an altitude of about one hundred kilometers the enhancement in the H and K lines is at least partially due to Ca^{++} emission. For lower altitudes and for the H line the cause has not been identified. The observed luminescence does not interfere with nighttime observations, but caution must be used in interpreting daytime observations of low level lunar luminescence.

Also during the past year Matson has started studying observations of red spots on the moon which have been reported during the last two centuries. To obtain a spectrum of a red spot one needs a high-speed, high-dispersion spectrograph. With the help of Dr. I. S. Bowen of Mt. Wilson and Palomar Observatories the optimum parameters of such a spectrograph have been determined.

4. RELATIONSHIP TO SPACE PROGRAM

For the last six years, a small but significant part of our research program under Grant NsG 56-60 has been devoted to background studies pertinent to the design and interpretation of experiments for future unmanned missions. Such studies rarely seem to warrant priority in the context of current flight programs, and yet equally rarely appear to be supported in the absence of specific missions. Thus again and again in the lunar and planetary program the situation has arisen where decisions suddenly had to be made regarding specific experiments for a new mission without adequate background data. The gathering of such data is not glamorous and probably would not be clearly justified from a completely detached point of view. However since both of the Principal Investigators have participated in the space program directly, and feel some share of the collective responsibility to provide the best possible foundation for future lunar and planetary missions, we have attempted to make some contribution through this grant. In addition, we have brought the problem, and suggested solutions, directly to the attention of Dr. Newell*. Our basic efforts have been aimed at developing sufficiently varied X-ray fluorescence analyses to ready that most useful tool for a future lunar or Martian mission (Dr. Brown) and to carry out specific analyses pertinent to the design and interpretation of future photographic missions (Dr. Murray).

In 1965, however, our annual funding level under Grant NsG 56-60 was significantly reduced. In addition some criticism has been directed at these background studies from time to time on the grounds they should be supported directly by flight programs - a position we feel not consistant with experience. However, our funding reduction has been significant enough that we have been forced to discontinue this kind of work. The X-ray fluorescence program was phased out during the first quarter of 1966, while very little effort,under this grant, has been devoted towards background studies related to photographic interpretation since the second quarter of 1965. It is to be hoped that the priority of such work will be examined by NASA.

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*By direct contact between Dr. Brown and Dr. Newell, and by a letter in August 1965 to Dr. Newell from Murray, Leighton, and Sharp.

6. SUMMARY OF PUBLICATIONS

a. PUBLICATIONS WHOLLY OR PARTIALLY SUPPORTED BY NASA GRANT NsG 56-60 FOR GRANT YEAR DEC. 1, '64 TO NOV. 30, '65

Murray, B. C., "A Martian Horror Story - Requirements vs Capabilities for the Photographic Exploration of Mars", Adv. in Astr. Sci., 19, 1965.

Murray, B. C., "Current Problems in the Interpretation of Lunar Physical Observations", (Summary of Remarks at Caltech-JPL Lunar and Planetary Conference, Sept. 1965, to be included in the Proceedings)

Murray, B. C., "Infrared Evidence of Differential Surface Processes on the Moon", (Summary of Remarks at the Royal Society Symposium on the Physics of the Moon, London, June 1965, to be included in the Proceedings)

Nichiporuk, W. and H. Brown, "The Distribution of Platinum and Palladium Metals in Iron Meteorites and in the Metal Phase of Ordinary Chondrites", J.G.R., 70, No. 2, pp. 459-470, 1965.

Short, J. M.* and C. A. Andersen**, "Electronprobe Analyses of Nickel Diffusion Gradients in Iron Meteorites and the Cooling History of the Meteorite Parent-Bodies", J.G.R., 70, No. 15, 1965.

Westphal, J. A., R. L. Wildey***, and B. C. Murray, "The 8-14 Micron Appearance of Venus Before the 1964 Conjunction", Ap. J., 142, No. 2, 1965.

Wildey, R. L., "On the Interpretation of Thermal Emission Maps of Jupiter", J.G.R., 70, No. 15, 1965.

Wildey, R. L., B. C. Murray, and J. A. Westphal, "Thermal Infrared Emission of the Jovian Disk", J.G.R., 70, No. 15, 1965.

Wildey, R. L., B. C. Murray, and J. A. Westphal, "The Eclipse Cooling of Ganymede", Letter to Editor, Ap. J., 141, p. 104, 1965.

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*** Present Address: Astrogeology Branch, U.S.G.S., Flagstaff, Arizona.

b. PUBLICATIONS WHOLLY OR PARTIALLY SUPPORTED BY NASA GRANT NsG 56-60 DEC. 1, '65 TO PRESENT

(Includes papers in preparation which will be submitted before June 30, '66)

Brown, Harrison, "Relationships Between Stars and Planets. I. The Abundance of Multiple-Star Systems and Invisible Companions", in preparation, 1966.

Brown, Harrison, "Relationships Between Stars and Planets. II. The Luminosity Function", in preparation, 1966.

Brown, Harrison, "Relationships Between Stars and Planets. III. Abundances of Planetary Systems", in preparation, 1966.

Brown, Harrison and Irene Goddard, "Statistical Study of Families of Asteroids", in preparation, 1966.

Kieffer, H. "The Effect of Chemical Layering on Planetary Dimensions", in preparation, 1966.

Leighton, R., and B. C. Murray, "Solid Vapor Equilibria of CO_2 and H_2O on Mars", (Submitted to Science).

McCord, Thomas B., "A Search for Lunar Luminescence", in preparation, 1966.

McCord, Thomas B., "Effects of Tidal Friction on the Neptune-Triton System", in preparation, 1966.

Murray, B. C., and J. A. Westphal, and R. L. Wildey, "The Lunar Nighttime Infrared Emission", in preparation, 1966.

Nichiporuk, W., E. Bingham, "Copper and Vanadium in Stony Meteorites", Presented at the AGU meeting in April, in preparation, 1966.

Nichiporuk, W., A. Chodos, E. Helin, and H. Brown, "Iron, Cobalt, Nickel, Calcium, Chromium, and Manganese Determination on Stony Meteorites by X-Ray Fluoresence", in preparation, 1966.

Westphal, James, "The Ten Micron Limb Darkening of Venus", JGR, in press, 1966.

Westphal, James, and E. E. Becklin, "Infrared Observations of Comet 1965f", Ap. J., in press, 1966.

c. PUBLICATIONS WHOLLY OR PARTIALLY SUPPORTED BY NASA GRANT NsG 56-60 FOR GRANT YEARS JAN. 1, '60 TO NOV. 30, '64

Brown, H., "The Density and Mass Distribution of Meteoritic Bodies in the Neighborhood of the Earth's Orbit", J.G.R., 65, No. 6, pp. 1679-1673, 1960.

Brown, H., "Addendum: The Density and Mass Distribution of Meteoritic Bodies in the Neighborhood of the Earth's Orbit", J.G.R., 66, No. 4, pp. 1316-1317, 1961.

Brown, H. "Planetary Systems Associated with Main Sequence Stars", Science, 145, No. 3637, pp. 1177-1181, 1964.

Brown, H., and Irene Goddard, "A Study of Some Non-Random Aspects of the Frequency of Meteorite Falls", Isotopic and Cosmic Chemistry, North-Holland Publishing Co., pp. 365-384, 1963.

Duke, M., D. Maynes, and H. Brown, "The Petrography and Chemical Composition of the Bruderheim Meteorite", J.G.R., 66, No. 10, pp. 3557-3563, 1961.

Millard, H. T., Jr., and H. Brown, "Meteoritic Time-of-Fall Patterns", Icarus, 2, No. 2, pp. 137-151, 1963.

Moore, C. B., and H. Brown, "Barium in Stony Meteorites", J.G.R., 68, No. 14, pp. 4293-4296, 1963.

Murray, B. C., "The Artificial Earth Satellite - A New Geodetic Tool", American Rocket Society Journal, pp. 924-931, 1961.

Murray, B. C., and A. B. Lees, "An Invariant' Property of Satellite Motion in a Dissipative Medium", Advances in the Astronautical Sciences, 8, pp. 294-302, 1962.

Murray, B. C., and R. L. Wildey, "Observations of Jupiter and the Galilean Satellites at 10 Microns", Ap. J., 139, No. 3, pp. 986-993, 1964.

Murray, B. C., and R. L. Wildey, "Stellar and Planetary Observations at 10 Microns", Ap. J., 137, No. 2, pp. 692-693, 1963.

Murray, B. C., and R. L. Wildey, "Surface Temperature Variations During the Lunar Nighttime", Ap. J., 139, No. 2, pp. 734-750, 1964.

Murray, B. C., R. L. Wildey, and J. A. Westphal, "Infrared Photometric Mapping of Venus Through the 8-14 Micron Atmospheric Window", J.G.R., 68, No. 16, pp. 4813-4818, 1963.

Murray, B. C., R. L. Wildey, and J. A. Westphal, "Venus: A Map of Its Brightness Temperature", Science, 140, No. 3565, pp. 391-392, 1963.

Nichiporuk, W., and H. Brown, "Platinum and Iridium Abundances in Meteorites", Phys. Rev. Letters, 9, No. 6, pp. 245-246, 1962.

Pogo, Alexander, "Annotated Bibliography of Physical Observations of the Moon", Division of Geological Sciences, California Institute of Technology, 1961.

Pohn, H., "New Measurements of Steep Lunar Slopes", P.A.S.P., 75, No. 443, pp. 186-187, 1963.

Pohn, H., B. C. Murray, and H. Brown, "New Applications of Lunar Shadow Studies", P.A.S.P., 74, No. 437, pp. 93-105, 1962.

Roddy, D.J., J. B. Rittenhouse, and R. F. Scott, "Dynamic Penetration Studies In Crushed Rock Under Atmospheric and Vacuum Conditions", A.I.A.A. Journal, 1, No. 4, pp. 868-873, 1963.

Watson, K., and C. A. Bauman, "Apparatus to Measure the Thermal Conductivity of Powders in Vacuum From 120-350°K", Rev. Sci. Instr., 34, No. 11, pp. 1235-1238, 1963.

Watson, K., B. C. Murray, and H. Brown, "Possible Presence of Ice on the Moon", J.G.R., 66, No. 5, pp. 1598-1600, 1961.

Watson, K., B. C. Murray, and H. Brown, "The Behavior of Volatiles on the Lunar Surface", J.G.R., 66, No. 9, pp. 3033-3045, 1961.

Watson, K., B. C. Murray, and H. Brown, "The Stability of Volatiles in the Solar System", Icarus, 1, No. 4, pp. 317-327, 1963.

Westphal, J. A., "New Observations of Atmospheric Emission and Absorption in the 8-14 Micron Region", Colloque International d'Astrophysique tenu a l'Universite de Liege, Memoires Soc. R. Sc. Liege, cinquieme serie, tome IX, pp. 360-361, 1964.

Westphal, J. A., B. C. Murray, and D. E. Martz, "An 8-14 Micron Infrared Astronomical Photometer", Applied Optics, 2, pp. 749-753, 1963.

Wildey, R. L., "A Computer Program for the Transformation of Lunar Observations from Celestial to Selenographic Coordinates", Icarus, 3, No. 2, pp. 136-150, 1964.

Wildey, R. L., "Hot Shadows of Jupiter", Science, 147, No. 3661, pp. 1035-1036, 1965.

Wildey, R. L., "Lunar Luminescence", P.A.S.P., 76, No. 449, pp. 112-114, 1964.

Wildey, R. L., "On Line-Blanketing Normalization of Subdwarf Photometry", Ap. J., 141, No. 3, pp. 943-948, 1965.

Wildey, R. L., "On the Infrared Opacity of Jupiter's Outer Atmosphere", Icarus, 3, No. 4, pp. 332-335, 1964.

Wildey, R. L., "Photometry of the Earth from Mariner II", J.G.R., 69, No. 21, pp. 4661-4672, 1964.

Wildey, R. L., "The Stellar Content of h and x Persei - Cluster and Association", Ap. J. Supplement Series, VIII, No. 84, pp. 439-496, 1964.

Wildey, R. L., "The Moon's Photometric Function", Nature, 200, p. 1056, 1964.

Wildey, R. L., and B. C. Murray, "10 Micron Photometry of 25 Stars From B8 to M7", Ap. J., 139, No. 2, pp. 435-441, 1964.

Wildey, R. L., and B. C. Murray, "Ten Micron Stellar Photometry - First Results and Future Prospects", Colloque International d'Astrophysique tenu a l Memoires Soc. R. Sc. Liege, cinquieme serie, tome IX, pp. 460-468, 1964.

Wildey, R. L. and H. A. Pohn, "Detailed Photoelectric Photometry of the Moon", A. J., 69, No. 8, pp. 619-634, 1964.