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SMITHSONIAN INSTITUTION
ASTROPHYSICAL OBSERVATORY

SATELLITE-TRACKING PROGRAM

Grant Number NGR 09-015-002

Semiannual Progress Report No. (22)
1 January to 30 June 1970

Project Director: Fred L. Whipple

Prepared for
National Aeronautics and Space Administration
Washington, D. C. 20546

Smithsonian Institution
Astrophysical Observatory
Cambridge, Massachusetts 02138

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INTRODUCTION

The most significant event of the past 6 months has been the completion of calculations for the 1969 Smithsonian Standard Earth (II). Results of this work, which represents a culmination of over a decade of satellite observations, mark a major milestone in the history of satellite geodesy and geoastronomy. Special Report No. 315 documents these efforts.

New models of the upper atmosphere that take into account the latest data from mass spectrometers on rockets and satellites and from thermosphere probes, measurements of EUV absorption, and data on satellite drag observed over a complete solar cycle have been successfully completed. They represent a considerable improvement over previous models and will be included in the COSPAR International Reference Atmosphere expected to be published in 1970 or 1971.

During the period of this report, the first of three new SAO laser systems was delivered and successfully tested at the Harvard College Observatory's field test site in Harvard, Massachusetts. This system, composed of laser transmitter, telescope photoreceiver, automatic pointing pedestal, and data- and range-recording electronics, is awaiting shipment to its permanent site at the astrophysical observing station in Natal, Brazil. The other two systems will be installed in Peru and South Africa. All three, along with the SAO laser/Baker-Nunn network, will participate in the forthcoming ISAGEX program.

In January 1970, the station in Comodoro Rivadavia, Argentina, was closed. The agreement with our cooperating agency, the Comision Nacional de Investigaciones Espaciales, remains in force, however, in the hope that we can embark on future cooperative programs.

RESEARCH PROGRAMS

GEODETTIC INVESTIGATIONS

Geopotential and Geophysical Studies

Final supporting calculations and comparisons for 1969 Smithsonian Standard Earth (II) have been completed during the past 6 months.

Drs. E. M. Gaposchkin and K. Lambeck have since documented a technical discussion of the methods and results in Special Report 315 (Gaposchkin and Lambeck, 1970), which has also been submitted to a scientific journal. Lambeck has interpreted the results in terms of datum shifts and has published his findings (Lambeck, 1970a). Investigations of tectonic and other geophysical implications have also begun.

A study of the uses of laser tracking for geodesy has been completed. The implications of precise laser range measurements for the dynamical methods of satellite geodesy have been documented by Gaposchkin (1970) and for the methods of geometrical geodesy by Lambeck (1970b).

Another activity occupying considerable time during this period has been the planning for the International Satellite Geodesy Experiment (ISAGEX). This program, organized by the Centre National d'Études Spatiales (CNES) in France, will result in coordinated observing by possibly 15 laser tracking systems with a global distribution. The Experiment Plan (CNES, 1970) provides a detailed description of the program.

SAO is the main orbit computation center for ISAGEX; as such, it will receive and process all the data to be used for predictions and will determine the prediction orbits for the laser satellites. Orbital elements will be communicated to the several computation centers for calculation of predicted look angles and ranges.

In planning for ISAGEX, SAO has evaluated the seven satellites* to be tracked in terms of the scientific results to be expected from a coordinated observing campaign. This evaluation, together with considerations of available personnel and other resources, has enabled SAO to make recommendations to the ISAGEX planning committee. In general, planning is proceeding well. SAO data-processing and communications groups are preparing to handle the large quantities of diverse data that we expect from ISAGEX.

Although SAO has concentrated on planning for ISAGEX, it has also attempted to maintain contact with several current international programs. For example, SAO was represented at the Western European Satellite Triangulation program (WEST) held in April in London, and at the Bucharest meeting of the Scientific Results from Observations of Artificial Satellites, held in June.

In conjunction with Gaposchkin's studies, Mr. J. R. Cherniack has spent considerable time developing perturbation formulas on the computer by using symbol-manipulation techniques. The main tool (SPASM) has been documented in Special Report 291 (Hall and Cherniack 1969). Wide interest in the scientific community is evident from the many requests for the program. Some effort has been devoted to providing a standard version that will run reliably on any CDC 6000-series computer.

The development of perturbation formulas is proceeding. The second-order determining function (S_2) used in Von Zeipel's method has been developed from first principles, has been shown to agree with the formula of Dr. Y. Kozai, and provides a check both on the classical formulas and on the computer programs.

*The following are to be tracked: 1964 64A, BE-B; 1965 32A, BE-C; 1965 89A, Geos 1; 1967 11A, D1C; 1967 14A, D1D; 1968 2A, Geos 2; PEOPLE (to be launched).

The perturbation formulas that have been developed are being checked against numerical integration of the equations of motion and against actual orbital data. These comparisons will also check the precision of the analytical formulas by Dr. S. Hamid.

Assisting Gaposchkin, Miss G. M. Mendes has been developing a conversion program, accurate to 3 cm to convert XYZ coordinates to $\lambda\phi\eta$, and vice versa. Furthermore, using the latest tesseral harmonics and station coordinates, she is calculating orbits every 4 days for use in redetermining the zonal harmonics.

As another part of the effort to increase analytical accuracy, Mr. J. Rolff has prepared a document on the numerical relation between the many Atomic and Universal Time scales used for satellite observations (Rolff, 1970). All SAO tracking data can now be expressed in a clearly understood, well-defined, and uniform time scale. These results will be published as an SAO Special Report.

In another area of geopotential studies, Dr. L. Sehnal has successfully completed his analysis for the computation of short-periodic perturbations of satellite orbits caused by solar-radiation pressure. This analysis has, in turn, been incorporated into a revised computer program for radiation pressure. Gaposchkin and his associates have begun to incorporate this revised theory into the orbit and gravity-field determination programs.

The magnetic field of the earth has also occupied a large amount of Sehnal's time. He has studied the motions of both magnetically stabilized and electrically charged satellites.

In still another area of geodetic and geophysical research, Dr. P. A. Mohr has established a geodimeter-theodolite network across the Ethiopian Rift Valley at latitude $8^{\circ}5$ N. This network will be remeasured in 1971 to detect crustal deformation, and the data will be applied to an analysis of plate tectonics of the African rift system.

Mohr has written a paper, based on data from his 1969 expedition, that details the structural significance of the Ethiopian dike swarm (Megrue and Mohr, 1970). He is also continuing work on a review of the geology of the African rift system (Baker, Mohr, and Williams, 1970). Also, at the A. G. U. annual general meeting, Mohr delivered a paper on problems concerning plate tectonics of the Afar Triple Junction (Mohr, 1970a) and another on the significance of contrasts between the volcanic chemistry of rift lava and that of plateau lava (Mohr, 1970b).

Laser and Interferometer Systems

The high-radiance neodymium-glass laser* for lunar-ranging experiments has been leased and delivered to the Agassiz Station of the Harvard College Observatory where a shelter for the equipment has been constructed by Messrs. W. F. Comerford and G. Veith. A small optical system, almost completed, will be integrated with the laser and tested on artificial satellites, while the construction of the larger optical system progresses. The present system has successfully achieved a 15-J output power level. This is sufficient for ranging to the moon. Wolf has written a lunar ephemeris program for the CDC 6400 computer to determine appropriate lunar observing times.

Lehr and Pearlman have experimented to improve laser ranging accuracy through analysis of return-pulse shape and amplitude. Their experiments have led to analysis of the quality of SAO's satellite predictions. A procedure for improving the accuracy of the laser range has been established, and 30- to 50-cm accuracy is possible. These results were presented at the Geos 2 review meeting (Lehr, Pearlman, and Scott, 1970).

*This activity was supported in part by NASA contract NASW-2014.

A procedure has also been devised for using simultaneous range measurements to detect the separation of two nearly collocated laser systems. The procedure was applied to the NASA-SAO collocation experiment at the Mt. Hopkins Observatory from October 1969 to January 1970.* Pearlman, Lehr, Mendes, and Wolf completed SAO's data analysis for this experiment. These results were also presented at the GEOS-B review meeting (1970).

Lehr and Pearlman have investigated a multiple-frequency probing system to study atmospheric refractive bias for both radio and optical measurements. Such a system is needed to reduce errors arising from atmospheric propagation effects.

During this same period, Dr. N. C. Mathur and his associates have made very long-baseline interferometric observations of the synchronous satellite ATS-5.† The observations were taken with the Agassiz 84-ft radio telescope at Harvard, Massachusetts, and with the 130-ft radio telescope at Owens Valley, California. The reduction of the data has led to substantial understanding of satellite VLBI. Fringes have been obtained on the satellite signal with various kinds of modulation, and the geometrical delay has been recovered.

The study of atmospheric effects on VLBI has also continued, using the ray-tracing program developed earlier. Mathur has discussed some estimates of the necessary corrections and described various probing techniques in a paper presented at the VLBI Symposium held in Charlottesville, Virginia, in April (Mathur, Grossi, and Pearlman, 1970).

* This activity was supported in part by NASA contract NAS 12-2129.

† This activity was supported in part by NASA contract NSR-09-015-079.

In connection with VLBI activities, it is appropriate to mention that the Hydrogen-Maser Program underway at SAO* has made considerable progress. Efforts in the past year have yielded data that will permit substantial improvements in the accuracy and stability of maser-clock systems, including those which will provide the frequency standards for VLBI activities.

*This activity was supported by NASA contract NSR 09-015-098.

ATMOSPHERIC INVESTIGATIONS

Atmospheric Investigations

Dr. L. G. Jacchia and his assistants have continued their investigations of the upper atmosphere through the analysis of the drag of artificial satellites. Tracking data for five artificial satellites with perigee heights between 250 and 1000 km have been reduced with high-precision techniques to provide a continuous monitoring of the manifold density variations of solar and geomagnetic origins.

A study of the diurnal density variation over a complete solar cycle (1958-1969) has revealed that the ratio of the maximum daytime temperature to the minimum nighttime temperature varies from the solar cycle with a phase lag of about 400 days behind the sunspot numbers or the decimetric solar flux. This is precisely the lag between solar and geomagnetic activity caused, in the course of the solar cycle, by the migration in latitude of the active areas on the sun that are responsible for the enhancement of the solar wind. The correlation coefficient between the temperature ratio and the 10.7-cm solar flux is only 0.59, while that between the ratio and the running yearly means of the planetary geomagnetic index K_p is 0.73. This discovery may have serious implications concerning the energy sources responsible for the heating of the upper atmosphere.

Much work has been done to construct models of the upper atmosphere that take into account the latest data obtained from mass spectrometers on rockets and satellites, from thermosphere probes, measurements of EUV absorption, and data on satellite drag observed over a complete solar cycle. Work on the models has now been successfully completed; they represent a considerable improvement over previous models and will be included in the forthcoming COSPAR International Reference Atmosphere to be published in 1970 or 1971.

Messrs. J. W. Slowey and I. G. Campbell, working in conjunction with Jacchia, have developed a new computer program, called SLAVE, that provides an ephemeris of the Keplerian elements of a satellite subject to the effects of the earth's gravity, solar-radiation pressure, and atmospheric-drag perturbations. The program is used to predict decay dates, to fill gaps in the orbital elements, and to provide the derivatives of the orbital elements for inclusion in DOI — all of which may greatly facilitate orbital computation.

Celestial Mechanics

The motion of artificial satellites has been the object of much of Hamid's efforts during the past 6 months. He has derived a formula for analytical computation of mixed gravitational and atmospheric-drag effects, using the Brouwer-Hori theory but with a more reasonable atmospheric model than that of the B-H theory.

Using Von Zeipel's method and Poincaré's variables, Hamid has also developed an outline for the general third-order planetary theory. In doing so, he eliminated the critical terms, i. e., the 2:5 and 1:2 inequalities of Jupiter-Saturn and Uranus-Neptune.

Dr. B. G. Marsden has established that the anomalies in the motion of Hidalgo are probably due to the error in the adopted mass of Saturn. The orbit of Hidalgo can apparently be used to determine the mass of Saturn quite well. (The result 3498.5 ± 0.3 m. e. has been obtained for the reciprocal.)

Marsden has also studied the motions of comets affected by relatively small nongravitational forces, particularly P/Faye and P/Tempel 2. The former is a clear example in which the transverse component has changed sign in recent decades. It is possible that its rotational axis may be nearly in its orbital plane. It is also possible that the transverse component of a comet may have this tendency of changing signs as it ages.

DATA ACQUISITION

OPERATIONS

Laser

Development of the new SAO second-generation laser system continued during this period. All three 20-in. photoreceivers and semiautomatic static pointing pedestals were accepted from Tinsley Laboratories, Inc. The first laser transmitter was accepted from Spacerays, Inc., the second is undergoing factory acceptance testing, and the third is undergoing preliminary tests.

The three ranging and data-recording electronic systems were completed at SAO, and all necessary modifications made. Electronics that will automate the laser tracking system have been designed and are being built. Automation will be achieved through direct reading of predictions from teletype tape.

All test equipment has been procured, and the major portion of the spare-parts package has been ordered.

System integration of the first laser transmitter, ranging and data-recording electronics, and pedestal control system was completed in Cambridge, and field testing was carried out at the Harvard College Observatory's Agassiz station in Harvard, Massachusetts (see Plate 1). All parts of the system performed well. Predictions were generated for the site, and 62 returns were obtained during the only 4-day period when weather conditions permitted ranging. Following the Agassiz tests, the system was crated for shipment to the station in Natal, Brazil.

The second and third photoreceivers and pedestals were shipped directly to stations in Arequipa, Peru, and Olifantsfontein, South Africa. The laser transmitters and ranging and recording electronics for these systems will be integrated and tested in Cambridge before being shipped.

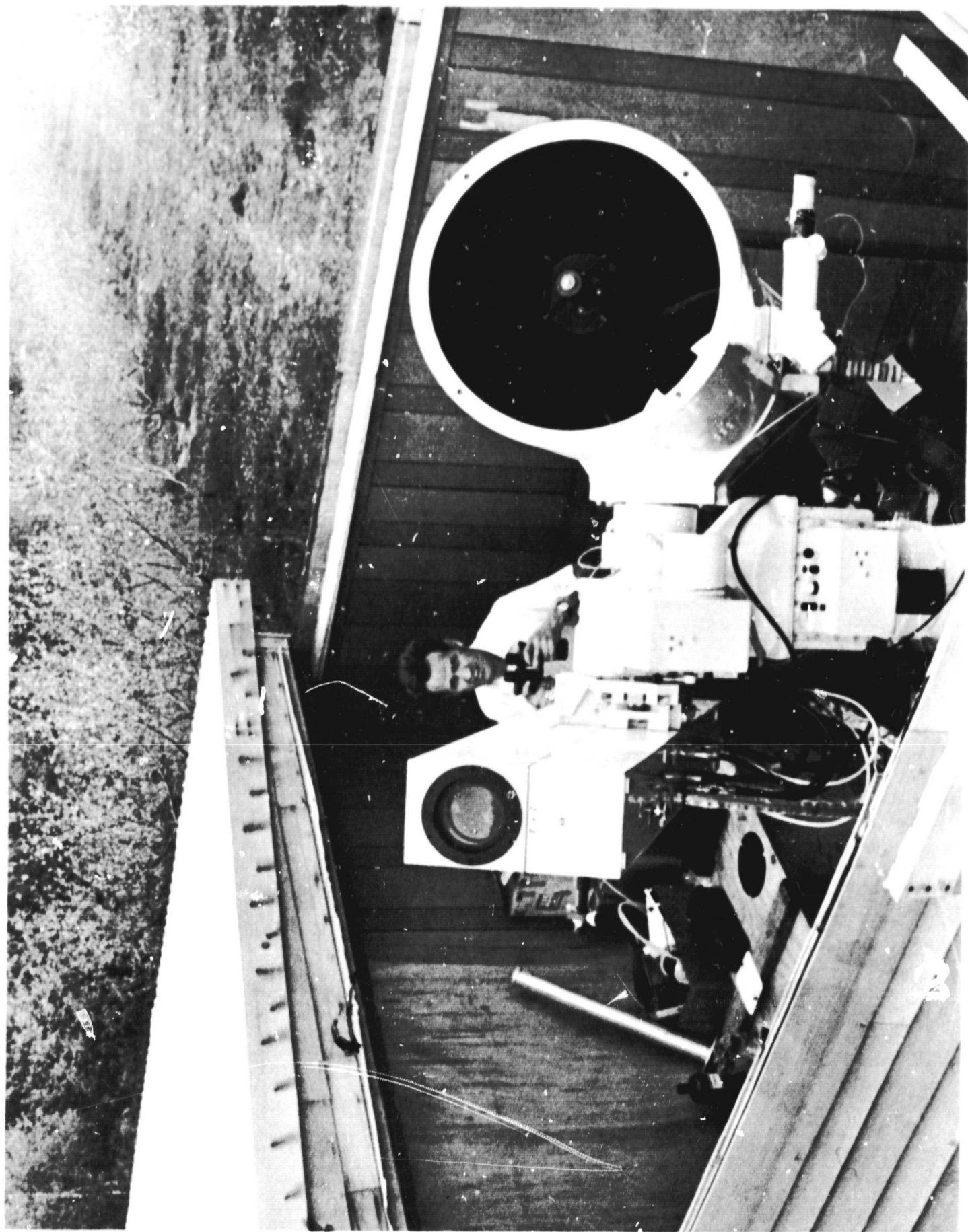


Plate 1. First new SAO laser system installed at the Agassiz field-test site in Harvard, Massachusetts, before shipment to its permanent site in Natal, Brazil. Laser Engineer Jakob Wohn, pictured, supervised testing of the equipment.

The Baker-Nunn cameras in Brazil and Peru have been moved to nearby locations so that the new laser systems can be installed in the former camera houses. At each location, a laser sole plate has been installed on the former camera pier and the site is ready to accept the laser system. Construction of a Baker-Nunn shelter is scheduled to commence shortly in South Africa, and a sole plate will be installed there once the camera is moved.

Collocation Experiment

The SAO/GSFC Arizona collocation experiment using the SAO Mt. Hopkins laser and the NASA mobile laser unit was successfully concluded on 31 January 1970.* The purpose of the 4-month experiment was to determine the relative accuracy of the two laser systems. Results show that they performed with a relative accuracy of 1 to 2 m. The displacement of the two lasers was determined to an accuracy of a few meters over a baseline of ~130 m. The experiment demonstrated that lasers are capable of ranging to an accuracy of 1 to 2 m with respect to one another. An additional result was that the laser data, when compared to Baker-Nunn data, appeared to be at least as good as the gravity model used in the calculations.

Atmospheric-Profile and Prediction Accuracy Studies

Studies to determine the accuracy of laser predictions continued. Whenever necessary, predictions can be updated in the field from Baker-Nunn data.

Atmospheric-profile measurements using the Mt. Hopkins laser system continued. The application of similar techniques to atmospheric-pollution measurements is being considered.

*This activity was supported in part by NASA contract NAS 12-2129 Task 11.

In June, the optical cavities of the Mt. Hopkins laser system were removed and returned to the manufacturer for replating. The new coating will eliminate the need for continual purging of the cavities with nitrogen.

Apollo 12

In January, special search predictions for the Apollo 12 Saturn 4-B booster rocket were sent to all stations. A week of observations produced no results, primarily owing to our inability to predict a good orbit because data obtained from optical and radar tracking systems were in conflict.

Apollo 13

Apollo 13 tracking support was provided by the Baker-Nunn cameras; however, since most major mission events were performed during daylight, photographic observation of them was not possible. Successful observations were made during the earth parking orbit and the translunar and transearth phases of the mission. One observation of a midcourse correction was obtained by the Mt. Hopkins station. All Apollo 13 films are being analyzed for images of fuel-cell/waste-water dumps and for midcourse corrections.

The SAO Moonwatch Division coordinated an international program of optical and photographic observations of the Apollo 13 spaceflight. Several astronomical observatories and scientific agencies throughout the world cooperated in making observations along with the Moonwatch network. Coverage included earth orbit and translunar and transearth coasts. The Apollo 13 translunar and transearth coasts were also observed with a 36-in. reflector and recorded on 4 hours of video tape by the Fernbank Science Center of Atlanta, Georgia. Optical and video-tape observations of the flight were recorded to distances of 200,000 miles and to magnitudes estimated to be as faint as 16.

The astrophysical observing station in Natal, Brazil, was contacted by representatives of the Brazilian government and, at their request, relayed Brazil's offer of assistance in support of the mission to the United States, for transmission to the appropriate U.S. government officials.

Comet Bennett

Throughout the spring, Comet Bennett was photographed periodically. During 4 to 6 May all stations having visibilities were requested to observe the comet every 15 min in an attempt to photograph the sunward streamers that sometimes develop as a comet passes through the earth's plane. Analysis of the films showed that no sunward spikes developed (see Plate 2).

A member of the Smithsonian astrophysical observing station crew in Woomera, Australia, made an independent discovery of Comet White-Ortiz-Bolelli (1970f).

Ohsumi

At the request of the Tokyo Astronomical Observatory, SAO provided tracking support for Ohsumi, the Japanese satellite launched 11 February 1970. Observations were made by the stations in Natal, Brazil; Mt. Hopkins, Arizona; and Island Lagoon, Australia, but data were insufficient to confirm an accurate orbit.

Geos Program

SAO support of the Geos 2 flash program ended on 13 January 1970, when the satellite ceased flashing. Following the Geos 2 launch in January 1968, the Baker-Nunn network obtained an estimated total of 7,400 successful

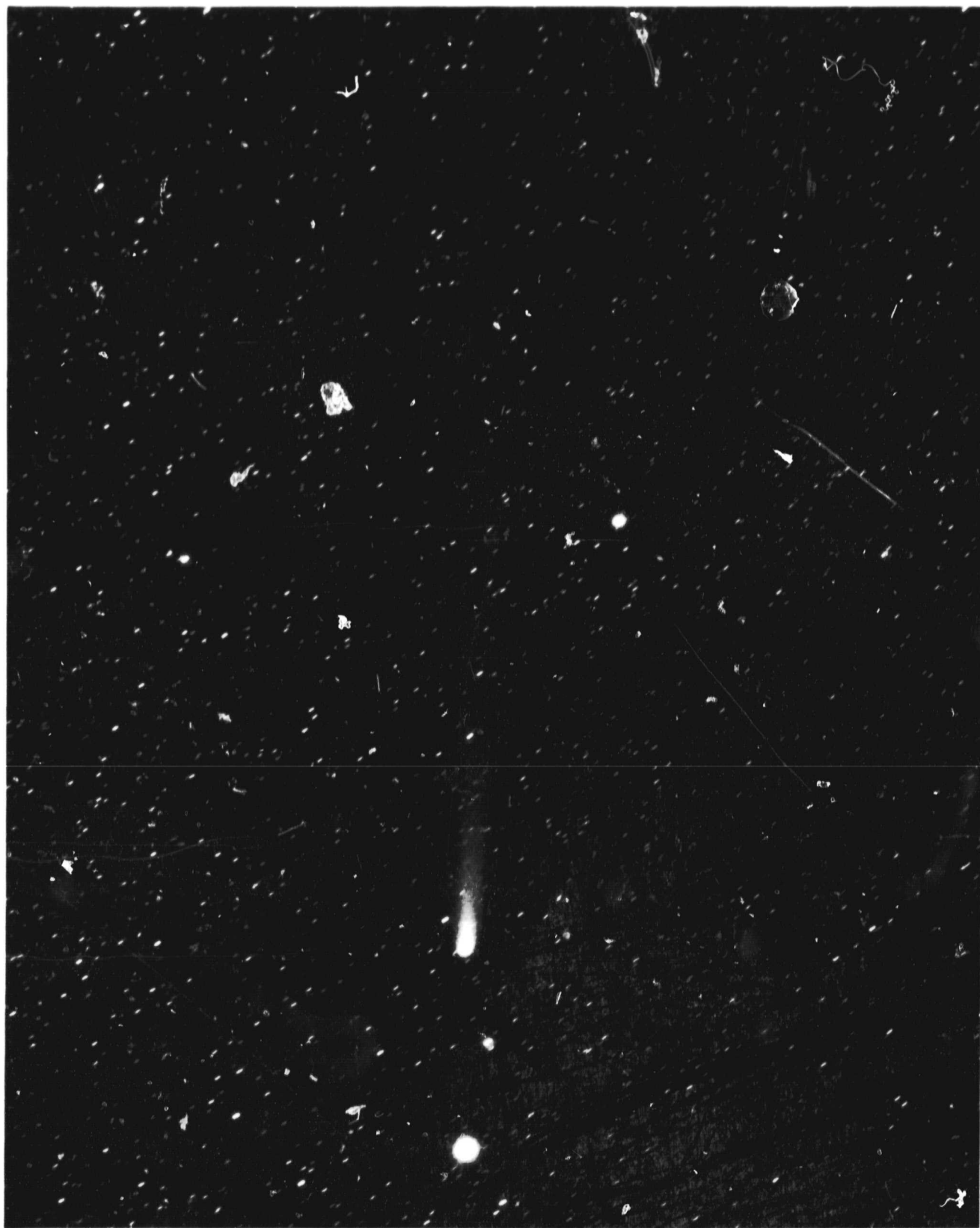


Plate 2. Photograph of Comet Bennett taken with the Baker-Nunn camera at the astrophysical observing station at Mt. Hopkins, Arizona, 4 May 1970.

flash observations and reported occasional malfunctions in the lamp-flashing system to the Geos Operations Control Center in Greenbelt, Maryland. SAO continues to track Geos 2 as part of its laser program and has increased the number of observation predictions in order to maintain an orbit suitable for laser observations without the flash sequences.

Mt. John

SAO continued its cooperative program with the U. S. Air Force to provide geometric ties between the recently established Air Force Baker-Nunn site at Mt. John, New Zealand, and the already established sites at Island Lagoon, Australia, and Sand Island, Johnston Island. A total of 100 simultaneous observations between Mt. John and Island Lagoon and 25 tracks between Mt. John and Sand Island are required. Each observation must consist of 10 good-quality data frames from each station. To date, 20 successful simultaneous observations have been made for the Island Lagoon-Mt. John tie, and 5 have been made for the Sand Island-Mt. John tie.

Comodoro Rivadavia

The station at Comodoro Rivadavia, Argentina, which became operational in November 1966, was closed on 29 January 1970. The Baker-Nunn camera, EEC timing system, and support equipment have been loaned, under special agreement, to the French Centre National d'Études Spatiales, which will operate the camera at Dakar, Senegal, in conjunction with a CNES laser system during the forthcoming ISAGEX experiment.

Operational Statistics

During this period, the two SAO laser systems recorded more than 990 successful range measurements. The Baker-Nunn cameras obtained a total of 8863 regular, simultaneous, and Geos flash observations. Table 1 (p. 21) lists all satellites tracked during this period.

Precision Timing and Associated Electronics

Average maximum possible timing uncertainty at the Smithsonian astrophysical observing stations as of 30 June 1970 was $\pm 90 \mu\text{sec}$. Eight time comparisons with portable clocks were made at the field stations during this period. Time at the Cambridge timing facility was maintained to within $\pm 5 \mu\text{sec}$ to U. S. Naval Observatory time.

Routine maintenance of the EEC0 timing system and associated electronics was carried out in Cambridge and at all field stations. Major maintenance was required at the station in Maui, Hawaii, as the result of a nearby lightning strike.

Protective devices were installed on all power lines and on the clock itself at the station at Mt. Hopkins, Arizona, in preparation for the summer lightning season.

Moonwatch

Moonwatch stations with registered site numbers now total 146. An additional 30 stations can be called on to observe satellite reentries and other nonroutine phenomena. Several world-renowned astrophysical and astronomical observatories have cooperated with Moonwatch in securing special observational data, such as photographic and spectrographic observations of Apollo command modules, components and cryogenic fuel and water dumps.

Moonwatch continues to administer the Volunteer Flight Officers Network (VFON) under an Air Force contract and expects to continue doing so in FY 71.* Provisions were also made under this agreement for Moonwatch to undertake the observing of selected satellites in highly elliptical orbits. Currently, the VFON encompasses 118 airlines located in 54 countries and flying over 2.6 million unduplicated air miles.

* This activity was supported by USAF contract F05603-70-C-0215.

During this period, optical observers reported 13,326 satellite observations. The special Moonwatch look-angle ephemeris was reinstated for a selected number of stations, the purpose being to help secure an increased number of satellite observations for further refining the model of several layers of the upper atmosphere. NORAD continued to send satellite-decay predictions to Moonwatch so that stations throughout the network could be alerted in time for possible observation. There were 156 satellite decays, of which 54 were predicted by NORAD. For these 54, Moonwatch calculated specific reentry look data and telegraphed this information to stations having possible visibility.

Arrangements between Aeronautical Radio Incorporated and the U. S. Air Force for real-time transmission of satellite-decay information to commercial airline pilots in flight are scheduled to begin about 1 July 1970.

An amateur radio link has been established between SAO headquarters and the Moonwatch station at Mendoza, Argentina. Scheduled contacts are made and special observing tasks and reports are transmitted and received. This method has proved so successful that steps will be taken to expand the amateur radio link to other areas of the world where some sporadic communications problems exist.

Preliminary discussions have been held for possible cooperative agreement to be made for the exchange of satellite-tracking observational information covering certain satellites between the French station at Kerguelen Island and Moonwatch headquarters. If discussions are successful, near real-time passing of orbital data will be accomplished via shortwave radio.

Other Activities

STADAD continues to provide, on a noninterference, no-cost basis, logistical and operational support for scientific and technical groups around the world, including our cooperating agencies. Some of the groups supported during this report period are the following:

1. Peabody Museum of Archaeology and Ethnology, Harvard University – cultural and historical research on a nomadic group in Ethiopia. Telegraphic communications and shipping support provided.

2. Optical Physics Laboratory, Air Force Cambridge Research Laboratory (AFCRL)–observations for determination of tropical atmospheric dust concentration. Photographic support provided, with equipment supplied by AFCRL.

3. Smithsonian Institution Center for Short-Lived Phenomena – collection of information on short-lived events and its dissemination to the international scientific community. Telegraphic communications support provided.

4. Geophysical Observatory of Haile Selassie I University, Ethiopia – geophysical research. Mail and telegraphic communications support provided.

5. Paris Institut d'Astrophysique – airglow observations at various wavelengths at the magnetic equator. Site facilities provided at the Ethiopia station.

6. Brazil/Max Planck Institute – barium-cloud experiment. Photographic support provided.

Communications

The SAO communications center reported normal operations for the period.

DATA PROCESSING

DATA SERVICES DIVISION

Weekly predictions on a total of 19 satellites (Table 1) were supplied to the astrophysical observing stations and Moonwatch sites. Simultaneous predictions were generated for the Air Force Baker-Nunn sites.

Laser predictions were provided for the SAO stations at Mt. Hopkins, Arizona, and Dionysos, Greece, and for the new lasers at Agassiz, Mass., for the Australian laser developed by the Weapons Research Establishment (WRE), and for the laser developed by AFCRL at Hanscom Field, Bedford, Massachusetts.

Orbital elements, predictions, field- and precisely reduced observations, and long-range forecasts were provided on request to SAO scientists, the Tokyo Astronomical Observatory, the U. S. Coast and Geodetic Survey, the Department of Defense, Langley Research Center, the University of London, CNES in France, WRE in Australia, and the Uttar Pradesh State Observatory, India.

Pageos and Geos 2 were used in a cooperative observing program with the Royal Radar Establishment at Malvern, England, and the European network of stations.

Solar-flux, planetary-index, polar-motion, and precise-timing data were received, tabulated, and distributed to interested persons in the scientific community.

The Film Control Section received and cataloged 9,139 films from Smithsonian stations and 858 films from Air Force stations.

TABLE 1. Satellites tracked from 1 January through 30 June 1970.

Tracked on request from NASA

<u>Satellite</u>	<u>Name</u>
1963 53 A	Explorer 19
1965 89 A	Geos 1
1966 56 A	Pageos 1
1968 2 A	Geos 2
1969 51 A	OGO 6
1969 99 B	Apollo 12 SIV B
1970 29 A	Apollo 13

Tracked for SAO Geodesy and Earth Physics

1959 Alpha 1	Vanguard 2
1960 Iota 2	Echo 1 Rocket
1961 Alpha Delta 1	Midas 4
1964 64 A	BE-B
1965 32 A	BE-C
1965 89 A	Geos 1
1966 56 A	Pageos 1
1967 11 A	D1C
1967 14 A	D1D
1968 2 A	Geos 2
1968 55 A	Explorer 38
1970 11 A	Ohsumi
1970 17 A	Dial-Wika

TABLE 1 (Cont.)

Tracked for SAO Atmospheric Investigations

<u>Satellite</u>	<u>Name</u>
1959 Alpha 1	Vanguard 2
1960 Xi 1	Explorer 8
1963 53 A	Explorer 19
1966 44 A	Explorer 32

A total of 2,458 precise reductions of satellite positions were completed, which brings the total of all reductions to 233,627 by 30 June 1970. Table 2 gives a breakdown of the satellite reductions made during this period.

Tape sales of and inquiries concerning the SAO Star Catalog continue to be handled routinely.

The Apollo 12 films are being analyzed with the use of the microdensitometer and special computer programs.

SAO is developing a cooperative plan to transfer certain photoreduction equipment to the University of Bologna, Italy. The University will provide photoreduction services at no cost to SAO and will serve as a small but continuing source of precise reductions for our atmospheric and geophysics programs. This service will partially compensate for the large decrease in work force within the SAO Photoreduction Division necessitated by the reduction in NASA funds. To assist in such a transfer, SAO is completing a manual detailing the operations in the precise reduction of satellite positions.

TABLE 2. Reductions completed 1 January to 30 June 1970.

<u>Object</u>	<u>Period</u>	<u>Program</u>	<u>No. of Images</u>
Explorer 19	March - August 1968	Atmosphere	749
Explorer 24	March - October 1968	Atmosphere	668
Geos 1	August - November 1968	Geometric Geodesy	578
Geos 2	Oct. 1969 - Jan. 1970	Geometric Geodesy	453
Apollo 12	November 15, 1969		10
Total			2458

PROGRAMMING DIVISION

The Programming Division is responsible for the development of computer programs for all phases of the Satellite-Tracking Program, for the operation of existing computer programs, and for development work in applied mathematics required to achieve these objectives. The computer programs are run on a Control Data 6400 located at 185 Alewife Brook Parkway.

Programs

SCROGE — A new version of SCROGE can make Baker-Nunn predictions over a longer time interval in the same run. A version that will synchronize the Baker-Nunn photographs with laser sightings is being designed. Maintenance of the blocked binary system with modifications to the backspacing routines has also continued. Copies of the SCROGE package have been sent to the French Space Agency and the Greek Atomic Energy Commission.

GRIPE — The program library for the 174 GRIPE programs, the mainstay of our geophysics research processing, has been finished and is now being updated approximately once every month. The preprocessing program library is now at the testing stage. Among other new features are the ELIMAT programs, which eliminate a standard GRIPE output matrix and produce a new tape with the reduced matrix.

DOI — Support has been supplied in modifying the DOI for laser observations.

Laser Prediction — Maintenance and minor additions continue to be provided to the laser prediction package. This program, together with preprocessing programs for laser observations, is slated for major revisions this summer as new equipment is put into operation at the stations.

SPASM - SPASM continues to be used for investigating Kozai's second-order oblateness theory. Use of the first-level development has resulted in redesign and expansion of the sophistication in this symbolic manipulation (see Special Report 291, Smithsonian Package and Symbolic Mathematics, by J. Cherniack and N. Hall).

A set of routines using disk storage for intermediate results has also been written for SPASM.

Miscellaneous

Work has also been accomplished on the following programs:

1. Comet ephemeris program,
2. Comet sorting program,
3. Problems in celestial mechanics.

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