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THE AFCRL LUNAR AND PLANETARY RESEARCH BRANCH

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Abstract: The Lunar and Planetary research program led by Dr John (Jack) Salisbury in the 1960s at the United States Air Force Cambridge Research Laboratories (AFCRL) investigated the surface characteristics of Solar System bodies. The Branch was one of the first groups to measure the infrared spectra of likely surface materials in the laboratory under appropriate vacuum and temperature conditions. The spectral atlases created from the results were then compared to photometric and spectral measurements obtained from ground- and balloon-based telescopes to infer the mineral compositions and physical conditions of the regoliths of the Moon, Mars and asteroids. Starting from scratch, the Branch initially sponsored observations of other groups while its in-house facilities were being constructed. The earliest contracted efforts include the spatially-resolved mapping of the Moon in the first half of the 1960s by Richard W. Shorthill and John W. Saari of the Boeing Scientific Research Laboratories in Seattle. This effort ultimately produced isophotal and isothermal contour maps of the Moon during a lunation and time-resolved thermal images of the eclipsed Moon. The Branch also sponsored probe rocket-based experiments flown by Riccardo Giacconi and his group at American Science and Engineering Inc. that produced the first observations of X-ray stars in 1962 and later the first interferometric measurement of the ozone and CO_2 emission in the upper atmosphere. The Branch also made early use of balloon-based measurements. This was a singular set of experiments, as these observations are among the very few mid-infrared astronomical measurements obtained from a balloon platform. Notable results of the AFCRL balloon flights were the mid-infrared spectra of the spatially-resolved Moon obtained with the University of Denver mid-infrared spectrometer on the Branch's balloon-borne 61-cm telescope during a 1968 flight. These observations remain among the best available. Salisbury also funded John Strong at the Johns Hopkins University for several near-infrared experiments which created a bit of a stir by detecting water vapor and ice high in the atmosphere of Venus. Once lunar geology transitioned from remote sensing to hands-on geology with the lunar landings, the Branch turned its attention to quantifying the thermal spectral emission from planets for their use as possible infrared calibration sources. The Branch and its research were phased out in 1976 when the program was terminated with the reorganization of AFCRL into the Air Force Geophysics Laboratory (AFGL).

Keywords: Moon, infrared, remote sensing, balloon experiments

1 INTRODUCTION

Quantitative thermal measurements of the Moon date to the 1860s with the studies of John Tyndall, Edward James Stone and William Huggins. However, Lord Rosse (1869; 1870; 1873) was the first to systematically quantify the radiant heat from the Moon by analyzing the disk-integrated lunar thermal properties. Rosse isolated the thermal emission from the Moon with measurements with and without a glass filter in the beam; all the lunar radiation gathered by his reflecting telescope impinged on the detector without the glass filter, while only the visible to near-infrared ($\lambda < \sim 2.5$ μm) sunlight reflected by the Moon got through the filter. Lord Rosse also presaged 'sky chopping' that was to become a standard infrared observing technique a century later (Sinton, 1986). He had found that the instabilities of his initial lunar measurements were related to the changing temperatures of the telescope and air. Consequently, he placed two identical thermopiles in the focal plane such that one viewed the Moon while the other looked at the sky next to the Moon, and the signals negatively combined to cancel the emission common to the beams.

Lord Rosse obtained fairly accurate disk integrated temperature profiles through a lunation and during an eclipse. Subsequently, lunar temperatures were occasionally updated during the next ninety years with observations obtained with gradually improving detectors. However, thermal measurements of the resolved disk of the eclipsing Moon were particularly interesting as the changes in the infrared fluxes could be continuously monitored over a relatively short time, hours instead of days for a lunation. Of the infrared pioneers in the first half of the twentieth century Edison Pettit and Seth Nicholson became the most prolific, systematically measuring infrared radiation from stars, the Moon and the bright planets with a vacuum thermocouple on the Mt. Wilson Observatory telescopes. They published thermal profiles across the full Moon and cooling curves near the limb during the 14 June 1927 eclipse (Pettit and Nicholson, 1930), while Pettit (1940) confirmed these earlier results by measuring the thermal profile near the sub-solar point for the 27 October 1939 eclipse. The measurements revealed a rapid decrease in the lunar brightness temperature with the onset of eclipse, from ~371K in full sunlight to ~200K shortly after the beginning of full eclipse. The brightness temperature then declined much more gradually during totality, from ~ 200K to ~175K with temperatures at the limb about 10K cooler. Paul Epstein (1929), a Caltech theoretical physicist, used Pettit and Nicholson's 1927 observations to deduce that the lunar surface was covered by a thin insulating layer of dust rather than just bare rock; Doel (1996) noted that this was the first quantitative analysis of conditions on another planet. Subsequently, Ryadov, Furashov and Sharonov (1964) derived the thermal inertia of the lunar surface from 8-13 μm observations between full Moon and 150° phase angle. Murray and Wildey (1964) obtained the more difficult to measure night side 8-14 μm lunar brightness temperatures while Low (1965) obtained analogous measurements at 20 μm.

As sparse as photometry/radiometry was during this time, spectral measurements were even more infrequent. Adel (1946) and Sinton and Strong (1960) had published 8-14 μm spectra of the sunlit Moon and of Mars, while Murcray (1965) obtained 8-14 μm spectra of the nearly full Moon on several nights in the fall of

1964 that were of sufficient quality to display subdued spectral structure.

This was the general state of lunar infrared measurements at the time that the Lunar-Planetary Research Branch of the Air Force Cambridge Research Center (AFCRC) initiated a multi-faceted research program to study conditions on Solar System bodies. The Branch built laboratory vacuum chambers to measure the spectra of candidate materials under simulated lunar temperature and vacuum conditions. The laboratory infrared spectra of the various materials thought likely to be found on the surfaces of the Moon, Mars and asteroids were assembled into a spectral library, which then could be compared with ground-based and balloon-borne infrared observations of these objects to infer their surface compositions. However, to provide the context as to why a military laboratory would be conducting basic research into the conditions of the Moon, brief descriptions of the origin of the Laboratories and how it operated within the larger arena of space exploration are given.

1.1 The Air Force Cambridge Research Laboratories (AFCRL)

To meet its research demands after WWII, the Department of Defense (DoD) turned to its few existing laboratories, such as the Naval Research Laboratory (NRL), and created new military laboratories.[1] In response, General H.H. (Hap) Arnold, the Commanding General of the Army Air Forces (AAF), tasked his Scientific Advisory Group led by Theodore von Kármán November 1944 to study and recommend how the AAF should best prepare for future research requirements. Von Kármán and the Advisory Group recommended that existing AAF developmental research facilities be expanded and new ones created (Gorn, 1994) under a budget of 5% of the wartime expenditure. Two AF basic research organizations were among the newly-created laboratories; the Cambridge Field Station and the Applied Research Section at the Wright-Patterson Air Force Base (AFB) (which was later renamed the Aerospace Research Laboratory).

In establishing the new Cambridge Field Station on 20 September 1945, the Army Air Force recruited among the electronics scientists and engineers who had worked on War-related radar and antenna research at the Massachusetts Institute of Technology (MIT) Radiation Laboratory, the largest such facility during the War, and the Harvard Radio Research Laboratory. The inducement to join this new organization was that about half the war-time military projects at these institutions were to be transferred into the Field Station. By the time the Air Force became a separate service in September 1947, the Field Station consisted of four electronics divisions. The subsequent transfer of the atmospheric sciences, meteorology and geophysics research at Watson Laboratory in Red Bank, New Jersey to Cambridge in June 1948 expanded the research mission for a newly-created Air Force Cambridge Research Center (AFCRC).

A decade later, AFCRC was slated for significant manpower and funding cuts under the Eisenhower administration's deficit reduction plans. Thus, the Secretary of Defense proposed a 10% cut in the fiscal year 1957 military research budget, which was to be achieved by cancelling 600 Air Force and Navy research projects (Rigden, 2007). In light of this situation, the Air Force planned to shift emphasis within the AFCRC to operations, development and system support and to rely on contracts with university and private research organizations for the necessary basic and applied research. This all changed as the Air Force responded to the Sputnik launch in October 1957 and subsequent demands to improve the technical research base within the DoD laboratories. Astronomical programs within AFCRC that were conducted in the 1950s, such as solar physics, cosmic ray and meteoritics research, enjoyed a resurgence, while new programs in lunar and planetary research and the infrared celestial background were started in the early 1960s. John Salisbury (pers. comm., 23 October 2004) provides a personal anecdote highlighting this change. He visited AFCRC in 1956 early in his graduate work as he anticipated being assigned there upon graduation. When asked what he was interested in Salisbury replied 'space physics'—much to the amusement of his interviewers. Four years later he led his own Branch in this field.

1.2 Partitioning Space

McDougall (1985) described in depth the U.S. policy on space and the attendant politics during the 1950s through 1960s, a summary of which follows. The developers of the V-2, Werner von Braun and his most experienced staff, were brought to the United States after the War, to continue rocket development under the aegis of the U.S. Army at Huntsville, Alabama. The Redstone was the first substantial rocket produced by the group, and the first flight occurred on 20 August 1953. About this time, the Army began developing the much larger Jupiter rocket and a special test vehicle, consisting of a Redstone first stage upon which were stacked two additional stages of clusters of small solid propellant motors, was devised for high velocity re-entry testing in support of the Jupiter development. Von Braun's team specifically designed this vehicle, called the Jupiter C, to have orbital capability by having it able to accommodate a fourth stage motor.

In July 1955, President Eisenhower announced that the United States would launch a satellite as part of the International Geophysical Year; the experimental objectives of which would be guided by the upper Atmosphere Research Panel, which had previously overseen experiments on V-2 rockets after the War. An intense struggle ensued between von Braun's group and the Naval Research Laboratory for the launch vehicle. The Administration decided upon the Navy's project Vanguard in September 1955. The Vanguard launch vehicle consisted of a modified Viking first stage with Aerobee and Altair second and third stages, respecttively. The Navy developed the Viking and Aerobee as research sounding rockets, which were used by academics and other experimenters, so the program had the decidedly desired 'civilian' flavor. However, as McDougall (1985) points out, the Army proposal, dubbed Project Orbiter, was recognized by the Government panel making the choice as having the better booster. Indeed, the Pentagon specifically ordered that a fourth stage motor was not to be included on the 16 November 1956 initial test flight to prevent an 'accidental' launch of a satellite into orbit.

The Administration's orderly approach to space was disrupted with the 4 October 1957 Sputnik launch. Sputnik caused a public furor that mixed national humiliation over having been beaten in the 'Space Race' with the specter of nuclear weapons in orbit. This was only compounded with the launch of Sputnik II a month later. The Vanguard program was accelerated in an attempt to launch a satellite on 6 December 1957 on the third of six test rounds originally scheduled; but it exploded seconds after launch. The next four attempts failed before the first success on 17 March 1958. In the interim, the Jupiter C was taken out of storage and von Braun's Army group successfully flew the first U.S. satellite, Explorer I, on 31 January 1958. A 'turf war' then ensued, as the services jockeyed to be the responsible agency for the U.S. space program. After extensive lobbying and numerous committee meetings, the Administration decided to elevate the civilian National Advisory Committee on Aeronautics (NACA) to agency status as the National Aeronautics and Space Administration (NASA) to lead the U.S. space effort. Thus, the U.S.'s open and peaceful program would be contrasted with Russia's secrecy. The roles of the Services were judged by their areas of responsibility and since the Navy emphasized sea power, it was eliminated early in the debate.[2] The Air Force was given the responsibility for the military use of space, due in part to its role in surveillance.

2 THE AFCRL LUNAR-PLANETARY EXPLORATION BRANCH

At the beginning of the 1960s, the roles of NASA and the Air Force in space were still being defined and preparatory research was essential to support the manned and unmanned missions contemplated. For example, manned exploration of the Moon was soon established as a goal, with the Air Force considering a manned lunar base (Brown, 1960). Many ambitious planners also had Mars penciled in as the next destination after the Moon. However, the exact nature of the lunar surface was a matter of conjecture at the time. Although most thought that the surface was covered by a thick layer of dust, some believed that the surface dust layer was loose enough to engulf any spacecraft that attempted to land (e.g. see Gold, 1959). The practical consequence of a deep loose dust layer that lacked appreciable bearing strength was that the foot pads on the Jet Propulsion Laboratory (JPL) Surveyor spacecraft would have to be so large to prevent the craft from sinking out of sight that there would be no room for experimental equipment (Salisbury, 2004).

Early on, Salisbury et al. (1963) resolved how far a landing craft would sink into the lunar dust by measuring a high vacuum adhesion for silicate particles and correctly predicting the bearing strength of the lunar surface, although not everyone was convinced at the time (Gold, 1965). The lunar surface properties also could be inferred by remote sensing with infrared spectral measurements. For example, the composition of the surface may be deduced from the infrared spectral signature indicative of its various mineral components while the relative strengths of these features are influenced by the size distribution of the soil in the lunar regolith (surface layer) and the packing of the particles. How hot the Moon gets during the daytime and how fast it cools with the onset of night or in eclipse also tells us something about the lunar surface; a rocky surface cools more slowly than a dusty one.

To address such issues, AFCRC had established the Lunar-Planetary Exploration Branch within the Research Instrumentation Laboratory in 1960, with Charles Campens as Chief and Dr John Salisbury as the single person workforce, to investigate the surface properties of the Moon and planets. Campens had written an internal proposal to map the Moon, which was funded, and the two-person branch was created to do the research after John Salisbury arrived. Salisbury had joined AFCRC in July 1959 to fulfill his Reserve Officer Training Corps military obligation after obtaining a Geology degree from Yale University; his interest in space geology dovetailed nicely with the objectives of the new Branch. He subsequently became the Branch Chief in 1961 when Campens migrated to JPL. The Branch's charter to assess the Moon as a manned station is evidenced by the fact that the second published Technical report from the group was titled *Location of a Lunar Base* (Salisbury and Campens, 1961); the first Technical Report was a brief 1960 review of what was then known about the Moon. The Branch was reassigned to the Space Physics laboratory in 1963 to reflect the basic research nature of the program.

As NASA began to ramp up planetary astronomy in the U.S., the Air Force also improved its in-house research capability to support space missions. On 1 April 1961 the status of basic research was elevated when all Air Force research was reconstituted into the Office of Aerospace Research (OAR), a separate operating agency that reported directly to Headquarters, U.S. Air Force. The Air Force Cambridge Research Laboratories (AFCRL—a recycling of the name as the facility was also so designated between 5 July 1949 and 28 June 1951) was the largest basic research component of OAR. Equally important, a number of civil service (pay scale) reforms designed to retain well-qualified Government researchers and to attract new talent were instituted in 1961-1962, and the manner in which the facilities and tools were funded were streamlined (see Berger, 1962).

The AFCRL lunar and planetary research benefited from these changes. Salisbury detailed the scope of the Branch's program to the Menzel (1962) panel in the winter of 1962. The Branch had inherited a number of research efforts funded by or through AFCRL such as lunar photography and mapping by the Pic du Midi Observatory (e.g. Kopal, 1960) and William Sinton's infrared radiometry and spectroscopy of the Moon (e.g. Geoffrion et al., 1960; Sinton 1962). Salisbury also planned to sponsor rocket-based X-ray and ultraviolet observations of the Moon and anticipated his own observatory facility. These observations were to be interpreted by measurements in the laboratory plus theoretical analysis. Salisbury emphasized that the program was tailored for the Air Force mission and that the research would complement that being done by NASA.

While in-house laboratory and observing facilities were being constructed at the beginning of the program, Salisbury and his team sponsored the efforts of others to obtain the observations in which they were interested. Salisbury and his Branch also periodically compiled summaries of Solar System research papers published in the literature as a resource for their research. The first bibliography of published lunar and planetary research plus a synopsis of the papers that were collected by Salisbury, Van Tassel and Adler (1962) comprised a mere 28 pages. By the time Salisbury (1968), as editor, published the 3rd Supplement in 1968, the bibliography had grown to a book-sized 304 pages. These annotated compilations were deemed important enough by the planetary research community that Salisbury and his team subsequently published them quarterly in *Icarus*, beginning with Volume 12 in 1970 and continuing until Volume 22 in 1973, after which they were published in the *Moon* through 1976 with Zdeněk Kopal as primary author.

2.1 Probe Rockets Experiments and X-ray Astronomy

The Cambridge Field Station was involved in space-based research from sounding rockets almost from the time it was formed. The military strongly supported geophysical research after WWII as it required this information for operations. For example, knowledge of the density, temperature and composition of the upper atmosphere was needed in order to understand how these factors influenced ballistic missile performance. Conditions in the ionospheric regions of the upper atmosphere affected radio communications and a link between solar activity and ionospheric disturbances was strongly suspected before the War. Also, it was speculated that solar ultraviolet radiation maintained the ionosphere, but direct measurements of the solar ultraviolet flux were needed to quantify this connection. How the Sun affects the ionosphere and, in turn, how the disturbed ionosphere perturbs radio propagation was, and still is, of high military importance.

The post-WWII military emphasis on upper atmospheric research came with a new tool—rocket probes. A civilian V-2 panel was established in February 1946 to organize and direct the upper atmospheric experiments that were flown on captured German V-2 rockets; although the panel was 'civilian-dominated', the panel members had been engaged in war-time research either while serving in the military or allied with one of the military-sponsored laboratories. These experiments were 'free rides' on the Army tests, from which the military expected to gain experience in missile operations, tracking and guidance and control. The broad range of experiments included studies of radio propagation in the ionosphere, atmospheric composition, pressure, temperature and density, cosmic rays, meteoritics, atmospheric absorption in the ultraviolet and ultraviolet energy distribution of the Sun. The Naval Research Laboratory and Applied Physics Laboratory (APL) had a leadership role on the panel with support from General Electric Corp.; other organizations, including several universities, also participated. David DeVorkin (1992) superbly chronicles the history of the US rocket-based upper atmospheric research conducted under the aegis of the panel from the initial post-War V-2 flights to the International Geophysics Year in 1957. The panel disbanded in 1961, having undergone several name changes during its 15 years of existence.

Both the Naval Research Laboratory and the Applied Physics Laboratory existed at the end of the War and both organizations had research groups that were adapted to conduct upper atmosphere experiments. In contrast, the newly-formed Cambridge Field Station had to catch up. Marcus O'Day, Chief of the Field Station's Navigation Laboratory, joined the V-2 panel a few months after it was formed and remained a member through the 1950s. He supervised the first successful Air Force V-2 (#15) launch from Holloman AFB, NM on 21 November 1946. Since O'Day's core professional staff originally was composed almost entirely of Ph.D. physicists recruited from war-time radar groups at Harvard and MIT, the disciplines of these scientists reflected the Navigation Branch's initial emphasis on electronics and radar research and, consequently, the first Air Force V-2 flights concentrated on ionospheric radio propagation. However, since O'Day coordinated the early Air Force work on the properties of the upper atmosphere, his branch was designated the Upper Air Laboratory in March of 1949 to reflect the importance of this research.

The V-2 experiments extended to higher altitudes and included *in situ* measurements of the density, temperature and constituents of the upper atmosphere, cosmic rays and solar ultraviolet radiation that were previously conducted from balloons. The ultraviolet transparency of the atmosphere is a direct measure of the ozone absorption profile as a function of altitude, which may be derived by measuring the ultraviolet spectrum of the Sun as it varies with altitude. On 10 October 1946, Richard Tousey's Naval Research Laboratory group obtained the first ultraviolet spectra of the Sun (Baum et al., 1946) with a spectrometer mounted in the V-2 tailfin. However, the Physics Department at the University of Colorado achieved the 'holy grail' of the first far ultraviolet detection of Solar Lα (Rense, 1953) on an 11 December 1952 Aerobee flight using a coronagraph and payload pointing control mechanism funded by O'Day. The key to their success was the significant improvement in attitude control.[3]

The 69th and last V-2 flew in September 1952. Of the various replacement options, the Aerobee[4] emerged as the workhorse for upper atmospheric and astronomical research. The numerous exo-atmospheric solar flux measurements obtained from these rockets were important in establishing the link between the changes in the Earth's climate and changes in the solar constant, and in showing that these changes drove the variations in density and height of the atmosphere that were being measured on rocket and balloon flights. At mid-century, an authoritative value for the variation in the solar constant was one percent or so (Doel, 1996). Thus, definitive measurements were needed to explore the Earth-Sun links to weather and, in this context, the first successful AFCRL Aerobee-based in-house experiment took place on 26 May 1950 to measure the solar constant.

AFCRC/AFCRL would fly rocket-based experiments at a frequency of about one per week; the majority of these flights were to probe the ionosphere. The Lunar and Planetary Research Branch sponsored a series of five probe rocket-based experiments, and the first two successful flights were historic as they were the first to detect X-ray stars.[5]

Salisbury funded a wide range of programs that provided the initial steps into several new fields of research. The X-ray results were, as Harwit (1981) noted, a specific example of how military research led to major astronomical discoveries. Giacconi (2009) recollects the events in some detail, so only a brief description is given here. In 1959 John Salisbury discussed the idea of a rocket-based X-ray lunar fluorescence experiment with Riccardo Giacconi, then at the American Science and Engineering Corp. (AS&E) in Cambridge, Massachusetts, although, as Giacconi (2009) noted, a calculation that he and his AS&E colleagues did at the time indicated that the expected fluorescence would be well below the detection limit of the proposed instrument. The first (unsuccessful) flight took place the following year. A second flight, on 18 June 1962, did not measure lunar fluorescence but did detect two objects, now design-nated Sco X-1 and Cyg X-1, outside the Solar System (Giacconi, et al., 1962). Two more AFCRL-sponsored experiments were flown in October 1962 and June 1963 that confirmed the discovery (Gursky, et al., 1963).

Giacconi (2005: 5-6) apparently is of the opinion that the discovery of the X-ray sources was due as much to preparation as to serendipity. He states:

> We were successful in interesting Dr. John Lindsay of the Goddard Space Flight Center … in funding a small program to develop grazing incidence telescopes but not in interesting NASA Headquarters in funding rocket instrumentation to search the sky for X-ray stars. We therefore turned to the Air Force Cambridge Research Laboratories that had funded previous work by ASE in the classified domain. The Air Force was receptive to providing support to place a small aperture (1 cm²) Geiger counter aboard a Nike-Asp rocket. The flight attempted in 1960 failed because of rocket misfiring. In January 1961 we received a new contract to fly four Aerobee 150 rockets for our experiments to search for X-ray stars, as well as lunar X-rays. The larger rocket permitted the design of a much more sensitive instrument …
>
> An important feature of the experiment was the use of a large field of view, which increased the probability of both observing a source anywhere in the sky and receiving a sufficient number of X-ray photons to make the detection statistically significant …
>
> After an-other rocket system failure in October 1961 we had a successful flight on June 18, 1962, when we discovered the first extrasolar X-ray source (Sco X-01) as well as the extragalactic X-ray background.

Note that Giacconi places the search for X-ray stars before measuring lunar X-ray fluorescence, the putative purpose of the experiments.

Salisbury funded AS&E for three more rocket-based experiments (Sodickson et al., 1968). The 26 May 1964 flight carried an X-ray package, but the pointing system failed. The 9 November 1965 Aerobee flight carried a Block Associates interferometer in an attempt to measure the 7-30 μm lunar spectrum at 40 cm^{-1} spectral resolution. The pointing system malfunctioned, and only two noisy unusable spectra of the Moon were extracted. However, as Baker, Steed and Stair (1981) pointed out, this experiment serendipitously obtained the first interferometric spectra of the Earth's limb in which the 15 μm CO_2 and 9.6 μm ozone bands were observed in absorption when the instrument looked at the Earth and in emission when viewed at a tangent height of 55 km above the Earth's horizon. The third and final experiment on 26 November 1966 carried a telescope with an infrared circular variable filter to obtained spectra of the Moon. After considerable data processing, 4-13 μm spectra of the lunar maria and highlands were extracted that revealed little difference between the two.

2.2 Ground-based Observations of the Moon

An indication of the difficulty that the Air Force shared with NASA in conducting lunar and planetary research in the early 1960s is that not only was most of the research done under contract but that non-astronomers (physicists) and academics were pressed into service. Such was the case for the infrared observations of the Boeing team of John Saari and Richard Shorthill. The initial lunar observations and analysis sponsored by AFCRL and Air Force Office of Scientific Research concentrated on lunar eclipses as the infrared measurements could follow most of a complete thermal cycle in just one night's observing. Such eclipse cooling curves were measured for several lunar features by Shorthill, Borough and Conley (1960), who used a thermistor bolometer with a 5-40 μm response to scan across the Moon during the 13 March 1960 eclipse. A brightness temperature of <200K was measured for the eclipsed lunar disc but they also found that certain features, such as the crater Tycho, stood out with a 50K brightness temperature contrast over their immediate surroundings. The Aristarchus and Copernicus craters also displayed similar enhanced emission. Sinton (1962) and Saari and Shorthill (1963) confirmed the 50K difference between Tycho and its surroundings at the beginning of the 5 September 1960 eclipse and Saari and Shorthill (1963; 1966) derived temperature contour maps for several craters the day before, during and after this eclipse. They also determined eclipse cooling curves for the craters. These observations simply scanned across the Moon and, thus, were able to only sample a limited area of the lunar surface. Then, Saari, Shorthill and Deaton (1966) obtained the first global infrared maps of the eclipsed Moon by raster scanning the entire disk with a 10″ beam using a Ge:Hg photoconductor with a 10-12 μm filter during the 19 December 1964 eclipse; a single image took 16 minutes to complete. These images revealed a large number of hot spots on the lunar surface, which were labeled as thermal anomalies; they were appreciably warmer than their surroundings. Ultimately, Shorthill and Saari (1966) tallied a total of about 1,000 hot spots, which Shorthill (1973) defined as discrete areas that are at least 5K above their surroundings. The preliminary classification of Saari and Shorthill (1967) associated about 85% of the hot spots with bright craters while another 9% corresponded to smalller isolated visible bright regions. Saari and Shorthill (1966) also converted the infrared images that covered areas selected as possible lunar landing sites into a set of isothermal (equal temperature) maps of the lunar equatorial regions, then synthesized isothermal and isophotal (equal brightness) visible and infrared atlases of the Moon throughout a lunation (Saari and Shorthill, 1967; Shorthill and Saari, 1965b).

Murray and Wildey (1964) found that the 8-14 μm thermal anomalies persisted for hours after sunset during a lunation and that, in concordance with eclipse observations, Tycho and Copernicus were the most prominent hot spots. Hunt and Salisbury (1967) subsequently tracked Tycho as it cooled for four days after sunset and Dave Allen and Ed Ney (1969) monitored the elevated temperatures of Tycho, Copernicus and Aristarchus over their surroundings during the lunar night. Allen (1971a) was able to detect the thermal hot spots near the terminator for a couple of days after sunset at 10 and 20 µm. Allen and Ney found that the observed night-time brightness temperatures of a given area on the Moon decreased with wavelength, with a difference of ~30 K between the 4.9 µm and 12 µm values. Their low resolution spectra confirmed that the 8-13 µm color temperature was significantly higher (~50K) than the brightness temperature.

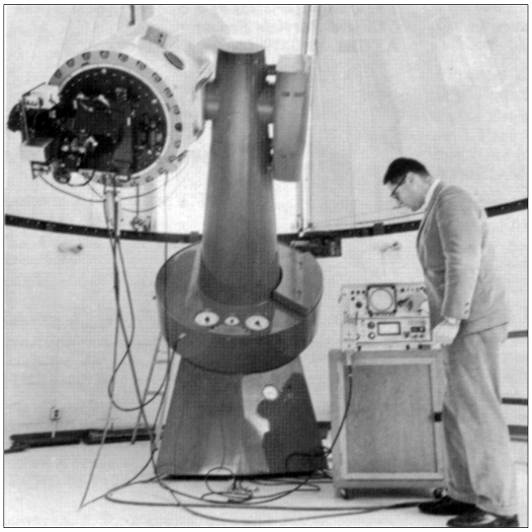

Figure 1: Dr John Salisbury at the controls of the Lunar and Planetary Research Branch's 60-cm telescope.

The Lunar and Planetary Branch planned their own observatory with which to obtain infrared observations. Smith and Salisbury (1962) detailed the results of a site survey conducted by New Mexico State University in the Cloudcroft area in the Sacramento Mountains of New Mexico as an initial step toward establish an AFCRL Lunar and Planetary observatory. Cloudcroft was chosen because the infrastructure (roads, electric power, etc.) were already in place, having been installed to support an AFCRC solar furnace that never materialized, plus the Air Force Avionics Laboratory had begun construction of a 1.22-m surveillance telescope at the site.[6] Furthermore, Holloman AFB and the AFCRL Sacramento Peak Observatory were close by and could provide administrative support. Since the Smith and Salisbury site survey had been limited by both time and money, the Air Force asked Donald Menzel (1962) to convene a panel to evaluate both the site survey results and the suitability of the site. The panel concluded that the site survey was inadequate and that "… sufficient time and funds should be spent to get a thorough check of the seeing conditions at more than one possible site …" (ibid.) with Sacramento Peak and Haleakala, Hawaii,[7] specifically mentioned in addition to Cloudcroft. Salisbury's group did not have the resources to conduct such a survey.[8] However, by the mid-1960s, the Lunar and Planetary Exploration Branch had constructed its own observing facilities, as shown in Figure 1. The telescope was one of the first 60 cm Boller & Chivens telescopes built (serial number 2), which the Branch sited in Concord, MA. This was an interim infrared lunar observatory, which was operated from the end of 1966 until November 1968 when a comparable instrument was opened on a permanent site atop Mauna Kea in Hawaii. Built with AFCRL funds, the Mauna Kea facility was jointly operated with the University of Hawaii. Hunt, Salisbury and Vincent (1968) used the telescope in Concord to map about 70% of the Moon at 10 µm during the 13 April 1968 eclipse looking for subtle changes in the (fainter) thermal anomalies since the Saari, Shorthill and Deaton maps of the December 1964 eclipse. Lunar transient events and the emission of volatiles had been observed since the time of Lord Rosse, and if, as speculated, the source of the emission was volcanic, then such phenomena might have infrared signatures as internal heat sources that might have varied between the 1964 and 1968 eclipses. They did not detect any internal heat sources nor did they find definitive changes in the brightness of the fainter anomalies between the times of the two eclipses.

The anomalously warm regions of the Moon seen in eclipse are surface areas that retain heat from absorbed sunlight longer than their surroundings. Unfortunately, deriving the thermal inertia of the resolved surface of the Moon is complicated by the fact that the cooling curves observed during the lunar night appear to differ from those observed during an eclipse. Wildey, Murray and Westphal (1967) proposed that such a difference was expected as the thermal emission during an eclipse comes from the very top-most layer of dust while the night-time emission arises from several centimeters below the surface. The temperature contrasts of the anomalies could arise if the areas were rocky and the cooler surrounding areas were covered by a layer of dust. However, since the lunar surface exterior to the thermal anomalies has the same low thermal inertia found for the Moon in general, a small proportion of the area (<10%) within the resolution element being used to observe the thermal anomalies and comprised of higher thermal inertia components such as boulders and large-scale surface roughness radiating at a higher temperature could explain the observations (Allen, 1971b; Allen and Ney, 1969). Although only a small proportion of the observed surface area, the higher temperature components dominate the thermal emission of the observations, especially at the shorter wavelengths.

While the infrared broadband photometry of the Moon provides information on the physical characteristics of the regolith, such as what terrain might be dusty or rocky and by how much, compositional information may be derived from the infrared emission spectra. Such spectra contain features indicative of the mineral composition, density, and particle size and packing. To explore these parameters, the Lunar and Planetary Exploration Branch created a spectral library from their laboratory measurements on likely lunar analog materials and used it to infer the mineral composition and surface properties of the Moon. These spectra were obtained in cooled vacuum chambers that simulated the temperatures and conditions on the Moon. Figure 2 shows an early laboratory vacuum chamber used to obtain the spectra of the candidate materials.

The most prominent spectral features between 8 and 25 μm are the fundamental stretching and bending modes of various types of silicate molecules, although grain size affects the exact wavelength of the peak and the shape and breadth of the features. The principle molecular vibration bands occur at what are classically labeled as the Christiansen frequencies of the minerals, where the maximum absorption or emission occurs at the wavelength at which particle scattering changes from being dominated by volume scattering to surface scattering. The vibrational and electronic bands combine linearly in a coarse mineral mixture (Thomson and Salisbury, 1993), which means the surface composition and the relative amount of the various constituents may be inferred by additively combining the spectra of individual minerals from the spectral atlas in various proportions until a match is found with observations. However, other factors influence the spectrum. Van Tassel and Simon (1964) concluded from early laboratory measurements that the strength of the infrared spectral signatures depended on particle size in the sense that the signatures were weaker in fine powder compared to coarser material, becoming barely discernable when the particles are the size of sand grains. Hunt and Logan (1972) extended and refined this analysis with detailed laboratory measurements on the effects that particle size has on the infrared spectrum for various silicate materials. Finally, the volume scattering of a small particle on a surface exhibits a ‘transparency’ or emission trough between the fundamental stretching and vibrational modes of silicates (Salisbury and Wald, 1992).

An observational database was needed with which to compare the laboratory spectra. To this end, Hunt and Salisbury (1964) obtained 16-24 μm spectra at four locations on the sunlit Moon using a Golay cell in a spectrometer mounted on the 1.07-m Lowell Observatory telescope. The spectra did, indeed, differ between locations: the 19-23.5 μm emission from Mare Serenitatis varied more steeply with wavelength than that from Copernicus. However, the atmospheric transmission impressed upon ground-based infrared spectroscopy dominated over the subtle mineral features in the lunar spectral energy distribution and one needed to get above the atmosphere to obtain uncontaminated measurements. Strong (1959) and de Vaucouleurs (1960) had posited early on that balloon-based astronomy could be a viable surrogate for satellites because, at altitude, a balloon platform is located above much of the atmosphere and the emission and absorption by atmospheric constituents are greatly reduced. Salisbury and Van Tassel (1962) also pointed out that much of the thermal emission from the atmosphere, which they believed had rendered ground-based determinations of brightness temperatures rather uncertain, would be eliminated at balloon altitudes.

2.3 The Balloon Program

AFCRC/AFCRL had been involved in balloon research since shortly after WWII and had actively advanced ballooning technology and applications. AFCRC/AFCRL and Holloman AFB combined have flown more than 2,500 balloon experiments over the years and have set the ballooning records for altitude, duration of flight and distance at one time or another. A bizarre side note is that Air Force operations from Holloman AFB, New Mexico, have been a major source for UFO mythology. The Air Force’s Watson Lab in Red Band, NJ (soon to join the Cambridge Field Station) funded New York University’s Project Mogul, a series of balloon flights that attempted to detect Soviet nuclear tests with acoustic sensors. The fourth flight in the series on 4 June 1947 and the first from Holloman AFB landed in a rancher’s field near Roswell, New Mexico. The recovery of the debris by the rancher plus later civilian observations of the recovery of anthropomorphic dummies dropped from Holloman-based balloon-borne parachute tests under Project High Dive gave rise to the ‘Roswell incident’. McAndrew (1995) has shown that this only became an incident in the 1970s with the publication of several lurid books about aliens, bodies and a crashed spaceship while McAndrew (1997) subsequently explained how the dummies and other incidents became the fodder for the Roswell UFO mythology. Ryan (1995), in his book: *The Pre-Astronauts: Manned Ballooning on the Threshold of Space*, tells the fascinating story of the manned balloon flights (Man High) in the early 1950s and the subsequent parachute tests with dummies (High Dive) and pilots (Excelsior) that culminated in Stargazer, a manned infrared astronomy flight.

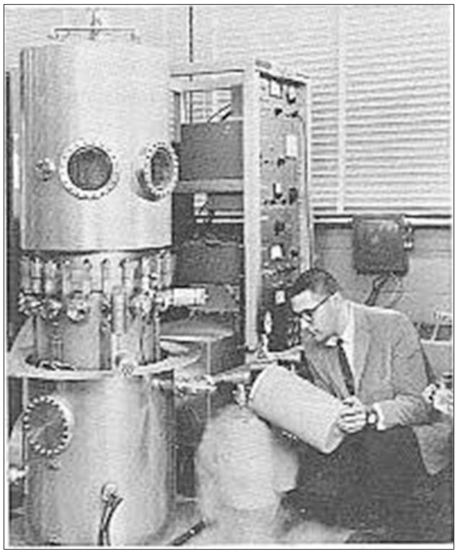

Figure 2: John Salisbury cooling the sample module for one of the environmental test chambers built and used by the Lunar-Planetary Exploration Branch to study the optical properties of candidate material that were thought likely to be found on the Moon, Mars and the asteroids.

While manned and unmanned balloons were used for cosmic ray research almost from the first ascent and optical observations were attempted in the mid-nineteenth century (e.g. Glaisher, 1863), quantitative optical astronomy from manned balloons began in earnest in the mid-1950s, principally due to the efforts of Audouin Dollfus at the Paris Observatory. In November 1956 and again in April 1957, Blackwell and Dollfus (Blackwell, Dewhirst and Dollfus, 1957; 1959) rode a balloon-borne gondola launched from the terrace of the Meudon Observatory to altitudes of between 5.5 km and 6 km to photograph solar granulation. Prior to that, on 30 May 1954, Dollfus became the first to obtain quantitative infrared observations from a balloon. He was carried to 7 km altitude in an attempt to measure water vapor on Mars with a lead sulfide cell on a 50-cm telescope. His rather clever detection scheme was thwarted by saturation of the 1.4 μm water band in the atmosphere above the balloon. Dollfus later followed this experiment in 1959 with near-infrared observations of Venus from 14 km altitude from which he derived the stratospheric water content which he used to calculate planetary values from subsequent mountain top measurements (Dollfus, 1964). Although these flights demonstrated that astronomy could be done from balloons, they returned limited quantitative results.

DeVorkin (1986) provides an in-depth and lively description of the circumstances, politics and personalities involved in the manned balloon flights in the first half of the twentieth century in his book *Race to the Stratosphere: Manned Scientific Ballooning in America*. However, his post-WWII description concentrates on the role of the Office of Naval Research in ballooning, and only passing reference is made to the extensive Air Force balloon program that Ryan (1992) documented in his book *The Pre-Astronauts*.

Shortly after Dollfus' experiments, the DoD sponsored two manned astronomical balloon flights. On 28 November 1959, Charlie Moore and Malcolm Ross attempted to observe Mars and water vapor on Venus with a 40.6-cm Schmidt telescope that had an effective aperture of 30.5-cm and was carried on board the Navy-sponsored Strato-Lab IV balloon flight, but they obtained limited results (Ryan, 1995). John Strong, at Johns Hopkins University, planned the observations and was originally scheduled to fly on this experiment. According to Augason and Spinrad (1965), Strong had designed the experiment which had 14 slits centered on isolated lines in the 1.13 water vapor band of the spectrum seen in the Czerny-Turner spectrometer. The multiple slits increased the flux onto the PbS detector, thus increasing the sensitivity of the measurements. However, the results were limited because swaying of the gondola made observations difficult, and an independent measure of residual atmosphere using the Moon was not possible. Also, Strong did not have a good value for the pressure in Venus' atmosphere, which compromised interpretation of the observation. A flight the previous year to observe Mars with the same instrumentation was canceled when the balloon ruptured. The second program, Project Stargazer, was initially proposed at the January 1958 AFCRC Balloon Conference as a series of four flights in the spring and fall of 1961. This was a joint Air Force, Navy, Smithsonian Institution and MIT program for manned balloon astronomy experiments; the Navy contributed a navy civilian astronomer, William White, while the most experienced Air Force balloonist, Joseph Kittenger, was to pilot the gondola. The first Project Stargazer experiment flew on 13 December 1962 and obtained observations with a 32-cm telescope mounted on top of the gondola that was remotely controlled from within. A few months later, Stargazer II was in the final countdown on 20 April 1963 when a static discharge tripped the balloon release, ending the experiment. Thus, the single Stargazer experiment became the seventh and final Air Force manned balloon flight in the program and, although labeled a "… huge success …" by the participating astronomers, Hynek and White (1963), stabilization problems and the expense of mounting such efforts resulted in the program being canceled before the Lunar and Planetary Research Branch's manned infrared lunar experiment could be flown.

As would later be the case for space-based astronomy, balloon researchers soon preferred remote operations without the weight and safety burden of manned gondolas, and both the Navy and the Air Force flew unmanned astronomical balloon experiments throughout the 1960s. The Office of Naval Research, the National Science Foundation, and NASA funded Princeton University for the Stratoscope II flights[9] that carried a 0.9-m telescope. The first two Stratoscope II experiments were flown in 1963 and obtained near-infrared spectra of cool giant and supergiant stars (Woolf, Schwarzschild and Rose, 1964), Jupiter, and Mars (Woolf, 1965). Danielson (1966) describes the hardware, details the flight operations and summarizes the results from the flights. Six more Stratoscope II flights obtained high-resolution photographs of galaxies before the telescope was irreparably damaged by ground impact.

The Lunar and Planetary Research Branch teamed with the AFCRL Balloon Branch in a three-phased program to obtain infrared measurements from balloons, the most ambitious of which was Project Stargazer. About the same time as Stargazer, AFOSR funded John Strong, at the Johns Hopkins University, through AFCRL, to conduct Project BalAst to loft a modest-sized instrument to an altitude of 24 km on an AFCRL unmanned balloon to measure water vapor, CO_2 and other gases in the atmosphere of Venus. Unfortunately, the instrument failed on the initial April 1962 attempt, but a second successful flight in February 1963 looked for but did not unambiguously detect the 1.3 μm band of H_2O; an October 1963 experiment extended the wavelength coverage to 3 μm to search for water (Bottema, Plummer and Strong, 1964). This was followed by AFCRL's Project Sky Top, which carried a near-infrared spectrometer to an altitude of ~33 km in January and February of 1963 to obtain thermal emission spectra of the Moon in an unsuccessful attempt to refine the lunar night-time temperature to better than the 50K accuracy of contemporary measurements. The University of Denver also received funding through AFCRL to fly an infrared spectrometer on an AFCRL balloon to measure the solar emission between 4 and 5 μm (Murcray, Murcray and Williams, 1964) as part of the long-term AFCRL interest in determining the solar constant. At an altitude of 31 km, the observations were relatively free of atmospheric interference and the solar flux measured by this experiment was one of a limited number of high-quality infrared observations used by Labs and Neckel (1968) to derive an absolutely-calibrated spectrum of the Sun. AFCRC had supported research at the Lowell Observatory during the 1950s for ground-based monitoring of the reflected sunlight from the planets looking for variations in the solar constant and to study the global circulation patterns on Mars and Jupiter as analogs for the Earth (Jerzykiewicz and Serkowski, 1966; Sinton, Johnson and Iriarte, 1959).

Salisbury's group had contracted with Alvin Howell and his associates at Tufts University to construct a payload for their in-house balloon-borne instruments to measure the infrared flux from the Moon and planets. Howell had an established relationship with the Hanscom balloon group, having built the instrument package for the first around the world balloon flight in 1957 (Long, 2004). The Lunar and Planetary gondola had a 61-cm telescope in a versatile payload capable of automatically acquiring and tracking any bright object in the sky; particularly, the Moon, Mars, and Venus. Van Tassel (1968) obtained 9-22 μm lunar spectra on the initial flight of this system in February 1966. He found no distinctive infrared spectral features that could be used for mineralogical identification. The 61-cm telescope and gondola package was flown 11 times between the first AFCRL launch in 1966 and five years later when the lunar measurements were terminated. Although only three of these experiments returned good data, Salisbury (2004) pointed out that the expense of a balloon flight was quite modest and the payload was recovered. Thus, the 'unsuccessful' flights could appropriately be considered as engineering development tests to perfect the hardware and flight procedures.

The most successful experiment mated the University of Denver spectrometer to the Tufts 61-cm telescope to obtain 7-13.5 μm spectra of six regions of the nearly full Moon on a 13 April 1968 flight (Murcray, Murcray and Williams, 1970). These results were a considerable improvement on Frank Murcray's ground-based measurements four years earlier (Murcray, 1965). The balloon-borne spectral energy distribution measured in each region was broader than could be accounted for by a single temperature blackbody, and the spectra were subtly different near the peak emission. In a companion paper, Salisbury et al. (1970) compared these results to the AFCRL spectral library but could not make any conclusive matches. Subsequently, Salisbury et al. (1995) found that additional simulation chamber measurements showed that the vacuum environment greatly enhanced the mid-infrared emission near the Christiansen frequency, broadening the spectral energy distribution and shifting the peak to shorter wavelengths. Thus, Salisbury and his colleagues were finally able to match the observed balloon-borne lunar spectra and infer that the lunar surface composition consisted of various combinations of silicate minerals.

2.4 A Slow Demise

With the manned landing on the Moon in July 1969, lunar studies went from remote sensing to hands-on geology, in which the Terrestrial Studies Branch duly participated (e.g. Logan et al., 1972). By this time, the primary military objective of the lunar research to characterize the environment that man and/or machines would encounter on the Moon had been achieved. The *1967–1970 AFCRL Report on Research* assessed the situation at the end of the decade:

> … long before Surveyor 3 had sent back to earth the first lunar photos of a disturbed soil, or the Apollo 11 and 12 astronauts stepped upon the moon, AFCRL scientists had derived what proved to be a valid model of lunar surface material. They concluded that the surface would be covered by a very fine powder, that it would be relatively firm and that the lunar powder would tend to adhere to all surfaces with which it came in contact.

Reorganization within AFCRL was initiated in 1970 as a consequence of Section 203 of the FY70 Military Procurement Authorization Act, dubbed the 'Mansfield Amendment', that mandated that all DoD research must demonstrate relevance to military systems or operations. The immediate consequence of the reorganization was moderate since most of the programs were able to be justified, and most of the people associated with those programs that could not be continued either retired or were reassigned. The Space Physics Laboratory was the most affected by the reorganization: the micrometeor research that dated to the mid-1950s (Explorer I had an AFCRC acoustic detector aboard) was terminated at the end of the fiscal year (June), as was the astrophysics research.[10] The infrared lunar observational program ended, and the Branch was reassigned to the Terrestrial Sciences Laboratory with a name change to the Spectroscopic Studies Branch to emphasize a new charter to determine the infrared spectral properties of the planets, particularly as to their suitability as infrared calibration sources.

AFCRL ceded ownership of a number of facilities at that time. Among them were astronomical facilities: in 1969 AFCRL gave up its interest in the Cerro Tololo 1.52-m telescope that was used for astrophysics. Similarly, Salisbury's recently-completed 61-cm planetary telescope on Mauna Kea was transferred to the University of Hawaii, becoming one of the worldwide network of instruments contributing to the NASA effort that Tatarewicz (1990) references. AFCRL also gave up its interest in the Arecibo telescope.

Salibury's Branch survived by changing its research objective to establishing the planets as infrared calibrators for space-based sensors, thereby demonstrating their program utility. Planets had always been a Branch interest, as indicated by the fact that Van Tassel and Salisbury (1964) measured the laboratory infrared spectra of the materials likely to be found on the surface of Mars. Indeed, Logan, Balsamo and Hunt (1973) mapped the 10.5-12.5 μm Martian surface brightness on the final flight of the 61-cm balloon borne telescope on 4 April 1971. The system was absolutely calibrated in flight by on-board direct comparisons with a black body and several surfaces of various infrared emissivities at fixed, known temperatures. These measurements were supported by a detailed analysis of the surface conditions (Balsamo and Salisbury, 1973) and composition of Mars (Hunt, Logan and Salisbury, 1973). Modern infrared astronomy was still in its infancy in the early 1970s and mid-infrared to submillimeter calibration references were sorely needed. The planets, especially Mars, were frequently used. Wright (1976) developed an empirical model for the absolute infrared flux emitted by Mars based, in part, on the Logan, Balsamo and Hunt observations and analyses that was used to calibrate the absolute flux of infrared/submillimeter observations and that from standard stars.

In 1974 the Branch was assigned to the Optical Physics Laboratory. To support the calibration objecttives of the Branch, a literature search and assessment by Cecil et al. (1973) indicated that Venus and Jupiter might be bright enough to serve as infrared calibrators. A new 1.27-m balloon-borne telescope built by Tufts University was flown in July 1974 to a 30-km altitude to measure the absolute irradiances from these planets. Logan et al. (1974) obtained whole-disk 4.5-16 µm circular variable filter spectra and made raster scans across Venus and Jupiter at a set wavelength. The measurements were calibrated by reference to an on-board black body and various flat plates of known emissivity and temperature, as describe by Logan, Balsamo and Hunt (1973). However, the observed spectral content of the objects revealed by these measurements compromised their value for calibration purposes.

The geophysics research in AFCRL was reconstituted as a new organization, the Air Force Geophysics Laboratory (AFGL), with an attendant reduction in staff. As part of the reduction, the Spectroscopic Studies Branch was formally disbanded on 30 June 1976. The people in the group were laid off, and the Laboratory disposed of the residual equipment. The mothballed 61-cm Boller and Chivans telescope at Hanscom AFB was given to the Phillips Academy, a preparatory school in Andover, MA. The two balloon-borne telescopes and platforms were sent to Mike Mumma at NASA Goddard Space Flight Center. Goddard never used the instruments, and eventually they were discarded. The Sacramento Peak Solar Observatory was transferred to the National Science Foundation and the AFGL on-site staff reduced from 45 to 7.

After leaving AFCRL, John Salisbury continued his distinguished career in infrared spectroscopy as it relates to planetary surfaces, including the Earth. He initially went to the Department of Energy, then the US Geological Survey and, ultimately to the Johns Hopkins University. He is currently retired. Graham Hunt went to the US Geological Survey where, unfortunately, his research in remote sensing of minerals associated with ore deposits was cut short by cancer. Lloyd Logan had a successful career at Perkin-Elmer, retiring as a senior manager. Peter Dybwad started his own company that manufactures easily-transported Fourier Transform infrared spectrometers.[11]

3 CONCLUSION

John Salisbury's assessment presented to the 1962 Menzel panel turned out to be quite correct: the AFCRL lunar and planetary research program was quite complementary to that developed by NASA. The research was unusual: it could be considered a complete investigation, as it combined telescopic infrared observations of the Moon and planets, laboratory observations under appropriate vacuum and temperature conditions of minerals likely to be found on this bodies, and theoretical analysis. However, emphasis was definitely on the laboratory experiments and interpretation, as the Branch scientists published about twice as many research papers on these results as on the observations during the nearly two decades of research at AFCRL. Part of this imbalance may be due to the fact that only four balloon experiments returned infrared observations worth publishing while none of the rocket-based data were adequate. The Branch did fund John Strong's balloon-based measurements of water vapor in the atmosphere of Venus; these were noteworthy at the time.

The best-known discovery with which the Branch is associated is the first detection of X-ray stars. Martin Harwit and Riccardo Giacconi have well highlighted John Salisbury's role in providing AFCRL support. Less spectacular, the atlas of mineral spectra is perhaps the most useful legacy of the Lunar and Planetary Research Branch, especially if Salisbury's continuation of this research at Johns Hopkins University is included. However, the Branch's balloon-borne experiments were unique, as they are the only successful mid-infrared astronomical balloon-borne program in the literature except for the marginal quality spectra to 7 µm from the first Stratoscope II flight (Danielson et al., 1964). A testament to the difficulty of mid-infrared astronomical measurements from a balloon is that Ed Ney, at the University of Minnesota, an innovator and pioneer in both ballooning and infrared astronomy, published nothing in the field. Ney had conducted balloon flights to measure solar cosmic rays in the late 1950s and the solar corona and inner zodiacal light in the early 1960s and his pioneering infrared astronomy is highlighted by Low, Rieke and Gehrz (2010). However, according to Martin Cohen (pers. comm., 9 January 2009) and Bob Gehrz (pers. comm., 17 August 2010), Ney did attempt several balloon-borne mid-infrared surveys with a 30.5-cm telescope in the late 1960s and early 1970s, but only the Moon and the umbilical cord of the balloon were detected.

Mid-infrared astronomical measurements from balloons are difficult for two reasons. First, despite the large reduction in atmospheric molecular band absorption and in the emission from the residual atmosphere above the balloon, the mid-infrared thermal emission from the telescope is still substantial as the telescope equilibrates with the stratospheric temperature of 250-260 K. Thus, the observations are limited to the brightest sources—the planets. More subtle is that, at the time the measurements were made, lunar and planetary radiometry and spectroscopy did not excite much interest in the astronomical community. On the other hand, the limited atmospheric interference in the mid-infrared did allow Murcray, Murcray and Williams (1970) to obtain the best thermal spectra of the Moon to date (Lucey, 1991).

4 NOTES

1. NRL is the oldest US military laboratory, dating from 1923. It arose from a recommendation by the Navy scientific advisory board chaired by Thomas Edison toward the end of World War I to create a modern naval research facility for development and engineering.
2. However, the Navy continued to be pre-eminent in research rockets for experimenters. Aerobee 150s were flown from the twin towers at Launch Complex 32 at White Sands Missile Range, which are about 75 meters from the ship-board launcher that the Navy used to test its operational missiles—the desert ship. Although White Sands is an Army base, the Navy has launch capabilities there that are similar to the missile launchers on a ship, which are dubbed the desert ship, and the Navy occasionally test fires naval missile ordinance from these facilities. The Navy also hosts the research rocket experiments that fly Black Brant sounding rockets out of Launch Complex 36. NRL also sponsored Space Vector Corporation in the early 1970s to develop the ARIES rocket from the second stage of the

Minute Man I. The first ARIES flew in 1973 and it was qualified at White Sands Missile Range in 1974. The ARIES is large enough to accommodate meter class optics in the payload and can loft ~700 kg (1500 lb) payloads to an altitude of approximately 360 km (225 miles), which permitted about 450 seconds of data acquisition.

3. Marcus O'Day's Upper Air Laboratory was disbanded in April 1953 and merged with other geophysics programs (Liebowitz, 2002). O'Day then became Superintendent of the newly created Advanced Research Laboratory, where he started a program in plasma physics. He retired several years later and died on 16 November 1961. A crater is named after him on the far side of the Moon to honor his pioneering space efforts and, in memoriam, AFRCL established the Marcus O'Day award in 1962 for the best annual scientific publication.
4. The Navy had sponsored James Van Allen, who was then at APL, to contract with the Aerojet Engineering Corporation in Pasadena, California, and the Douglas Aircraft Company to develop an inexpensive liquid-fueled rocket capable of lifting 100 lbs. to 100 miles altitude. Aerojet, a 1942 industrial spinoff of von Kármán and colleagues at the Caltech Guggenheim Aeronautical Laboratory, was renamed the Jet Propulsion Laboratory in 1944, and it supported the APL air-breathing ram-jet Project Bumblebee program and Aerobee, combining the names of the sponsoring project (Bumblebee) with that of its Aerojet developer. The first Aerobee was launched in September 1946 and 1,037 Aerobees of various types were flown by the time the rocket was retired in 1985. The Aerobee was eventually supplanted by less expensive or more capable vehicles in the late 1980s. The last Laboratory Aerobee was launched on 19 April 1983 and, aptly, carried a solar ultraviolet experiment.
5. These X-ray observations opened this wavelength regime to astronomical exploration. The following three experiments attempted X-ray and infrared observations of the Moon and were less successful.
6. The Air Force Avionics Laboratory at Wright-Patterson AFB began constructing a four-axis 1.22-m (48-in) telescope at Cloudcroft in 1962; but the instrument was unsuitable for planetary research. The facility became operational in 1964 and was used for optical measurements on satellites throughout the decade. Lambert and Kissell (2000; 2006) describe the facility and its use for surveillance for the next decade, after which AFGL astronomers monitored the variability of solar-type stars (e.g. see Worden, 1983). In 1994 NASA replaced the 1.22 m telescope with a liquid mirror instrument to monitor space debris.
7. The Harvard astronomers were aware that the Advanced Research Projects Agency (ARPA) planned to install telescopes on Mt. Haleakala. The University of Michigan originally developed two 91.4-cm telescopes under ARPA sponsorship for visible and infrared observations. Construction began in 1963, with limited operations commencing in 1965 and full commissioning of the site in 1969. ARPA solicited interest from the astronomers who attended a 5 April 1962 meeting at Harvard University in using the infrared telescopes, but apparently the offer was not pursued.
8. The Menzel panel did not appreciate the then-labyrinthine Air Force approval process for facility construction that prevented Salisbury from setting aside funds for another site survey and constructing the observatory. General B.G. Holzman (1962), AFCRL Commander from September 1960 to October 1964, describes these difficulties, using as his example the solar furnace that was supposed to be built at Cloudcroft. Both the Menzel panel and Tatarewicz were puzzled as to why this facility failed to materialize. The furnace was to provide the high temperatures needed for growing crystals and to conduct metallurgical experiments. The furnace was a multimillion dollar project first proposed in 1954 and dropped in 1960. Although the project was approved and funds allocated at various levels, the value of the project would be questioned by someone in the annual approval process. However, by 1960s the researchers who advocated the furnace found laboratory alternatives to the furnace with the felicitous outcome that the military budget cycle with its three to four year delay for facilities construction actually saved money and produced a better alternative (laboratory facilities) in this situation.
9. Stratoscope I was a late 1950s solar experiment.
10. The optical astrophysics program studied plasmas and how they interact with magnetic fields. This program provided the seed money in 1958 for the Cerro Tololo project (Doel, 1996) a collaborative effort with Yerkes Observatory for the site survey in the Chilean Andes for a 1.52-m telescope. The National Science Foundation funded site development and shared the cost of the telescope with AFCRL. The telescope was completed in 1966, and Space Physics Laboratory astronomers sporadically observed there. The branch also used shock tubes to derive radiative lifetimes of elemental lines important to astrophysics.
11. John Salisbury (2004) kindly supplied the information regarding the fate of the people in the Lunar-Planetary Branch.
12. The Air Force Technical Reports listed below may be accessed through the Defense Technical Information Service (http://www.dtic.mil/dtic/) using the identifier at the end of the reference. NASA and many AF publications are accessible through the National Technical Information Service (http://www ntis.gov/).

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