UTAH STATE UNIVERSITY, AURORAL RESEARCH, AND THE COLD WAR

Paul Concidine

Department of History
Utah State University
Logan, UT 84341

On November 19, 1976, a Talos-Castor rocket left the Poker Flat Research Range near Fairbanks, Alaska. Prepared by a team of engineers from Utah State University, the primary scientific instruments on board were two high power electron accelerators designed to shoot powerful beams of electrons into the atmosphere, thus creating artificial aurora. Though one of the accelerators experienced a short circuit, the other produced the desired electron beam up to and as the rocket reached its apogee at 265 kilometers, and then throughout its descent to approximately 84 kilometers.[1] This particular launch, however, was merely a test of the electron guns and other accompanying instruments, and therefore provided valuable data that would later be used to produce and measure artificial aurora.

As was the case in this launch, many of the experiments performed by researchers from Utah State University during the 1970s were concerned with the electromagnetic phenomena associated with aurora. For various reasons, most of them military, a great deal of attention was given to the infrared spectra produced by aurora, and many technologies were developed in an effort to understand them. In addition to exploring the major objectives and technologies of these auroral studies in general, this paper will focus specifically on some of the major projects taken on by Utah scientists and engineers during the decade, including the ICECAP series, the EXCEDE project, as well as the Field Widened Interferometer (FWI) and Rocketborne Field Widened Interferometer (RBFWI) projects. By no means do these programs constitute all of the work done by the labs during this time. They were, however, the largest and most scientifically significant tasks, and are characteristic of the research objectives that dominated the decade for the engineers and scientists at the USU labs. The auroral investigations of the 1970s were sponsored by military organizations for reasons of national defense, and in some cases were an experimental extension of the atmospheric nuclear testing programs of earlier decades.

During the spring and summer of 1970, the core of UARL moved from the University of Utah in Salt Lake City to Utah State University in Logan, Utah, and changed its name to Space Science Laboratory.[2] In addition to Kay D. Baker, who had been appointed director of UARL in 1967, ten other scientists and engineers made the move to Logan.[3]

The other major space research group at Utah State University was Electro Dynamics Laboratories, which specialized in infrared aerospace research and was founded in 1959.[4] Though Space Science Laboratory and Electro Dynamics Laboratories did not officially merge into Space Dynamics Laboratories until 1982, much of their research was performed in concert throughout the 1970s.[5]

A major research concern of the scientists and engineers at these labs throughout the decade was auroral phenomena. UARL scientists actually launched their first auroral experiment on July 26, 1963 from Churchill Research Range, and others followed in 1964, 1965, 1966, and 1969.[6] In March of 1972, two rockets with atmospheric sensors were launched from Poker Flat Research Range (PFRR), which became the major launch site for aurora studies.[7]

Auroral phenomena occur in both the northern and southern hemispheres. The aurora borealis, or "northern Lights," result from complex interactions between the Earth's atmosphere, its electric and magnetic fields, and energetic particles such as protons and electrons from the Sun. When these energetic particles approach the Earth, some are trapped by its magnetic fields and are pulled into its atmosphere, where they collide with atoms and molecules. These energetic collisions cause the release of photons in the form of electromagnetic spectra of various wavelengths, which we witness as the brilliant colors of aurora from the visible part of the spectrum.[8] Auroras occur most frequently in two, ring-shaped bands called auroral ovals, which encircle the Earth's northern and southern magnetic poles, respectively.

Auroral research was important to the Air Force Cambridge Research Laboratory (which today is called the Air Force Research Laboratory, AFGR), the Department of Defense (DoD), and the Defense Nuclear Agency (DNA)—the major sponsors of this research—for several reasons. First was the interference of aurora on radio communications. During auroral activity, artificially produced radio waves can be disrupted to the point that radio communication to and from polar communities and military installations, as well as to aircraft in the area, becomes unreliable. In the hostile environment of the polar region such disturbances can be fatal.[9] Specifically, the disruptive qualities of auroras posed challenges to the Ballistic Missile Early Warning System (BMEWS), a system of radar installations established in the late 1950s. In the event of a ballistic missile attack over the North Pole, this early warning system would be required to detect and track the missiles, or "cold bodies," against a background of the Earth's atmosphere. Precise modeling of the atmosphere's transmissive and emissive properties at all wavelengths was therefore of prime importance. Auroral research would help scientists to find solutions to these problems, or a least to forecast the timing and magnitude of auroral clutter effects.[10]

Kay Baker explained a related reason for the concern about aurora: ". . . ionization is very key; if somebody wanted to knock out your communications, they would launch a rocket, knock off a nuclear weapon, and it ionizes the whole atmosphere and blacks out radio communications."[11] By launching a ballistic missile and detonating its nuclear warhead high above the Ballistic Missile Early Warning System's radar installations, the Soviets could disable the United States' ability to detect and track subsequent missiles. In fact, aurora's effect on the earth's ionosphere was understood to be "qualitatively identical to the atmospheric excitation caused by nuclear energy deposition,"[12] i.e., the influence of a high altitude nuclear detonation. Since the Limited Test Ban Treaty prohibited all atmospheric testing of nuclear weapons in 1962, auroral studies could supplement the knowledge about these blasts that had been gained from atmospheric nuclear tests performed before the treaty.

Utah atmospheric researchers were especially interested in the infrared emissions of aurora. Typically described as heat radiation, infrared light is not visible to the human eye and is composed of photons with wavelengths greater than about 700 nanometers.[13]

This region of the electromagnetic spectrum attracted the interest of the U.S. military during the Cold War for several reasons, some of which are discussed very generally in a brochure entitled *Infrared Energy Research at Electro-Dynamics Laboratories*. The brochure states: "The use of infrared sensors for surveillance is of major importance to our national defense early warning systems. Orbiting airborne or ground based sensors can be used to detect rocket launchings or ground based maneuvers by foreign powers. Such activities are revealed as perturbations against the naturally occurring infrared backgrounds.[14]"

In short, since all matter naturally emits infrared radiation, these wavelengths could be used as an alternate method to radar (which requires a radio signal to be reflected off the target) for the detection and tracking of ICBM's. But since aurora also produced infrared emissions, researchers had to learn to distinguish between targets and natural backgrounds.

"CIRRIS 1a: Description and Capabilities," which details a major project undertaken by Space Dynamics Laboratories in the 1980s, discusses these issues: "The infrared spectral region from 2.5 μm to 25 μm is particularly important in both target detection and predictive modeling. . . . At certain wavelengths, spectral windows' exist in the infrared region, through which sensors can observe targets with little or no atmospheric interference. The AFGL/DNA experiments are aimed, in part, at precisely defining these spectral windows and in modeling the effects of various atmospheric disturbances on them, since those disturbances will affect sensor response.[15]

Infrared research therefore sought not only to characterize natural infrared emissions (from both quiescent atmospheric backgrounds and disturbed, such as those caused by auroras and nuclear detonations), it also sought to precisely define the spectral windows through which "cold bodies," such as ICBMs, could be viewed and easily identified against the naturally occurring infrared background.

In a very real sense, these early auroral investigations were an effort to gain the same kind of data that had been gleaned from the U.S. military's high-altitude nuclear tests, which had been discontinued by the Limited Test Ban Treaty of 1962. At that time the military determined that ". . . measurements sufficient to understand the entirety of the conditions [associated with high-altitude nuclear explosions] were not accomplished before the discontinuation of atmospheric testing of nuclear weapons by the United States."[16] Despite the cessation of atmospheric detonations, the instrument development program that produced the technologies to study nuclear detonations was not discontinued in 1962.[17] It was therefore proposed that these instruments be put to use in "polar regions where the concentrations of magnetic fields provides conditions of energetic particle fluxes (natural auroral phenomena) with atmospheric ionization, heating, and light emissions not completely unlike those found in a post nuclear situation."[18] It was primarily to this end that the 1960s aurora experiments were conducted.

Air Force Cambridge Research Laboratories, and consequently the space and atmospheric research institutions at USU, first became interested in the infrared emissions of aurora around 1970. A report produced by Space Science Laboratory in 1972 explained that "The interest in auroral infrared measurements precipitates from recent observations of these phenomena, speculation as to extent of their effect upon our nation's defense systems, and the use of these emissions to help in understanding the controlling atmospheric processes."[19] Another report from 1974 states: "Investigations into the auroral phenomena have, in fact, been continuing for many years, but recent measurements have revealed that in conjunction with some visual auroral activity, infrared emissions of previously unsuspected proportions may also be present. . . . These phenomena . . . cannot be ignored since they must be accompanied by significant changes in the chemistry of the regions involved, and understanding of the controlling chemical reactions is vital to the well-being of our nation.[20]"

ICECAP (Infrared Chemistry Experiments-Coordinated Auroral Program) was one part of the Defense Nuclear Agency's HAES (High Altitude Effects Simulation) program, which was initiated in early 1970.[21] Space Science Laboratory designed rocketborne payloads and conducted many experiments for ICECAP, which had the broad goal of "providing information ascertained as essential for the development and validation of predictive computer codes designed for use with high priority DoD radar, communications, and optical defensive systems."[22] Another report states that "These [predictive computer codes] are needed to assess and evaluate the operation of critical DoD radar and optical systems in nuclear disturbed environments."[23] Like the aurora experiments of the 1960s, ICECAP was in many ways related to the objectives of atmospheric nuclear testing.

Atmospheric infrared research posed unique engineering challenges. Since all warm matter gives off infrared radiation in the form of heat radiation, any infrared sensor that is not cooled to a sufficiently low temperature will pollute its field of view with its own radiation. In order to surmount this problem, USU engineers had to find ways to effectively cool their instrumentation. In the 1970s, liquid helium, liquid nitrogen, and other elements were used to cryogenically cool infrared sensors. This experience made the USU laboratories leaders in the science and technologies of cryogenics.[24]

The auroral experiments performed in the 1960s by UARL researchers were usually conducted at Churchill Research Range near Manitoba, Canada.[25] Building on their experience from prior decades, UARL scientists launched sensors into active aurora aboard various rockets and thereby provided valuable *in situ* data. In contrast to most things American, in the world of electrical engineering smaller is better, and thanks to miniaturization of instrumentation, it became possible to include many different sensors on a single rocket payload.[26]

By 1972, auroral researchers had modeled a relationship between auroral activity and concentrations of certain key atmospheric chemical constituents—especially NO, NO^+, CO_2, OH, and O_2. When excited by collisions with energetic particles from the sun, these molecules emitted much of the infrared radiation associated with aurora.[27]

When energetically excited, atoms and molecules give off electromagnetic energy (photons) of specific wavelengths, called emission spectra, which can be used to identify the atom or molecule.[28] These photons result from changes of state in electron energy, or from vibrational energy level changes.[29] Taking atmospheric measurements of emission spectra, therefore, would provide important information on the molecules and atoms present in the atmosphere, and the chemical reactions they might be involved in. The first two ICECAP 72 rockets—flown on March 6, 1972 and March 9, 1972 respectively, were designed to investigate "atmospheric OH chemistry through its associated infrared emissions."[30] The other payload from ICECAP 72—Black Brant 17.110-3—focused primarily, though not exclusively, on

NO, its chemical precursors, and other species which "could represent the end fate of NO as well as other auroral parameters"[31] and was described as "the prime experiment in the ICECAP 72 coordinated auroral measurements program."[32]

The ICECAP 72 payloads were among the first USU rocketborne payloads to require cryogenic cooling systems. Though sources are unclear, the first helium cooled spectrometer ever to be flown aboard a rocket was probably the one launched aboard a Black Brant VC by USU researchers on March 24, 1971 at Churchill Research Range.[33] All three of the ICECAP 72 payloads were cooled with liquid nitrogen.

Astrobee D 30.205-3 and Astrobee D 30.205-4 made another important innovation. Since the instruments carried by the Astrobee D rockets were carried in the mid-section of the rocket, and were designed to look forward with respect to the long axis of the rocket, the nose-tip had to be ejected during flight in order to expose the instrumentation.[34] This was accomplished by a system of timers and electronic guillotines housed in the nose-tip, which sheared the bolts holding the two halves of the clam-shell type nose-tip together, and were completely independent of other rocket circuitry.[35] By initiating separation from the rear, or bottom of the nose-tip, and thus exposing instrumentation, these launches demonstrated an effective new technology.[36]

As previously mentioned, the Astrobee rockets launched on March 6 and March 9, 1972, were designed to study OH in association with aurora. In order to make contrasting measurements, the first was launched into a "quiet nighttime sky with respect to OH enhancement", and the second was launched into "a medium bright auroral display accompanied by indicated OH enhancement."[37] Both launches were successful, and all instrumentation, as well as nose-tip separation, performed as designed.[38] Black Brant17.110-3, launched on March 16, 1972, was also successful. The instruments on board gathered data on NO concentrations by analyzing a specific range of IR spectra, which also gave important information on relevant chemical reaction rates and the total ionospheric input-output energy balance associated with aurora.[39] It was launched into a bright auroral arc, functioned as designed, and collected extensive data.[40]

USU researchers performed these auroral experiments for the ICECAP program through March of 1975. Some of the rockets used in this series were recovered, refurbished and reused. Such was the case for Black Brant 18.219-1, launched on February 25, 1974. This payload was originally launched on March 27, 1973 as Black Brant 18.205-1, and was recovered and flown a third time in 1975.[41] Though the precise instrumentation aboard the ICECAP rockets varied through the years, two specific areas of 2º Infrared spectra were commonly measured throughout the project: Long Wave Infrared (LWIR), and Short Wave Infrared (SWIR). An important investigation into LWIR spectra, which, as the name implies, consists of 2º Infrared radiation of longer wavelengths, was performed on March 22, 1973 as part of ICECAP 73A.[42] This rocket, Black Brant 18.006-2, "was the first to yield a complete altitude profile of the LWIR emission spectrum both on ascent and descent under auroral conditions."[43] SWIR emissions, which extend only to about 6 micrometers, also received considerable attention, in part because of the predominance of OH and NO spectra in this region.[44] These emissions could only be detected above the Earth's lower atmosphere, which blocks them.

In the early 1970s, Infrared emission of the shortest wavelengths, called Near Infrared (NIR, defined as approximately 1-2.75 micrometers), were also of interest but difficult to measure because of technological limitations—existing spectrometers were too slow to follow rapid variations in the spectral region involved.[45] This region was of interest to the Air Force because of the impact it could have on "defensive systems."[46] In order to overcome the technological limitations, engineers and scientists at Electro-Dynamics Laboratories (EDL), in conjunction with AFCRL and with support from the Defense Nuclear Agency, began working on a ground based spectrometer capable of taking fast measurements in the NIR region, called the field-widened interferometer (FWI).[47] The intention behind the design of this instrument was therefore to "provide systems analysts with the requisite infrared measurement data that they [could] apply to their computer codes to predict the effects of artificially-stimulated atmospheres."[48] The Field Widened Interferometer was also developed as part of ICECAP.

The FWI used a configuration of mobile and stationary mirrors to achieve a large etendue (viewing field), which was necessary to make quick, high resolution spectral measurements in the 1-3 micrometer range.[49] The Field Widened

Interferometer was a variation of the standard Michelson interferometer-spectrometer.[50] An interferometer is a device which separates light into two beams which can optically interfere with one another to produce an interferogram. A spectrometer disperses light into a color spectrum. The major innovation of Electro-Dynamics Laboratories' device was its inclusion of a wedge shaped end mirror which could be moved forward or back such that it introduced more or less optical material into the light beam.[51]

Though at first the FWI was only used to take measurements from the ground, EDL engineers later formatted it for installation and flight aboard a KC 135 aircraft.[52] By November 1977, it was adapted for rocketborne flight and was being flown on developmental flights into aurora at Poker Flat Research Range.[53] It was then called the Rocket-Borne Field Widened Interferometer (RBFWI). In order to achieve the desired wavelength sensitivity, the FWI and RBFWI were cryogenically cooled with liquid nitrogen and liquid helium.[54]

EDL scientists used the FWI to record near-infrared spectra from many locations, including Logan Canyon, Utah, but most auroral measurements were taken from the mobile USU observatory (ARGUS) at Poker Flat Research Range. These measurements provided valuable data, but because of the emission absorption and masking effects typically encountered by ground based infrared observations, the measurements were not as complete as *in-situ* measurements.[55]

The first developmental flight of the RBFWI took place at Poker Flat Research Range on November 13, 1977.[56] Sergeant rocket number IC 730.09-1 lifted the device, along with a photometer and an energy deposition scintillator (which measured the energy input from electrons in the region scanned by the RBFWI), into a post-breakup auroral glow.[57] The primary objectives of this flight were to "flight test the newly developed 1.5 to 8.0 µm [micrometer] cryogenically cooled interferometer-spectrometer, and to recover the instrument for future flights. Consequently, the payload was instrumented for parachute recovery in addition to the measurements instrumentation.[58] Since the spectral range of the FWI extended only to 2.9 micrometers, in addition to testing the adaptation of the FWI to rocket flight, the November 13, 1977 launch was a test of the RBFWI's spectral range, which had been extended to 8 micrometers.[59] USU researchers conducted the second developmental flight of the RBFWI on November 13, 1978, at Poker Flat Research Range.[60] Due to the failure of the RBFWI's pop cover seal and consequent heating which led to instrument saturation, no data were collected during this flight.[61] Other important developmental data were recorded, however, and the major instruments parachuted and were recovered without damage.[62]

On April 13, 1983, USU researchers launched the RBFWI, aboard Sergeant Rocket number 30.276, into aurora above Poker Flat Research Range.[63] The interferometer withstood the effects of the rocket's vibration, maintained alignment, and recorded an "excellent spectral profile . . . in the 2 to 8 µm range."[64] Despite its success, this was the last flight of the RBFWI. According to Kay Baker, this project was discontinued for economic reasons. "[We] did quite a bit of selling to try to get that instrument or that type of instrument flown again. But I think it was sort of a change of procedure in the government. . . . Things were going more and more towards big projects . . . that sort of took up most of the budget. . . . the shuttle itself started taking a lot more of the budget . . ."[65]

The final major auroral project USU researchers worked on in the 1970s was EXCEDE. This project, which was also associated with the Defense Nuclear Agency's High Altitude Effects Simulation program, was an important project for the USU space research labs during the 1970s and into the 1980s.[66] The basic concept behind EXCEDE, which was conceived of by Dr. A.J. Stair in 1971, was to use high-powered, rocket-borne electron accelerators, or "guns," to fire blasts of electrons into the earth's atmosphere, thus creating artificial aurora, while simultaneously recording these auroras. Producing such atmospheric effects had several advantages. First, since the energy that produced these aurora, or input energy, would be precisely known, the energy dynamics of the aurora could be more accurately analyzed than they could in naturally occurring aurora.[67] Also, since the auroras produced were spatially localized, they were easier to monitor and record.[68] The flights associated with this project are summarized in Table 1.

Table 1. 1970s Atmospheric Dosing Flights Associated with EXCEDE[69]

Vehicle—Vehicle Number	Launch Date	Experiment	Results
Nike-Hydac EX 401.41-1	Oct. 17, 1974	PRECEDE	Good Data
Castor C 75-1	April 13, 1975	EXCEDE II (test)	Good
Sergeant EX 530.42-1	Feb. 28, 1976	EXCEDE (SWIR)	Good
Talos-Castor EX 651.92-1	Nov. 19, 1976	EXCEDE	Good
Aerobee 170 AO 4.602	Dec. 12, 1977	PRECEDE II	Good Data
Talos-Castor EX 851.44-1	Oct. 29, 1978	EXCEDE II (Spectral)	No Data
Talos-Castor A51.970	Oct. 19, 1979	EXCEDE II (re-flight)	Good Data

The military objectives behind the EXCEDE project, as was the case with ICECAP, were related to nuclear effects. One project report states: "Project EXCEDE is a program to ionize large amounts of air in the upper atmosphere in order to study in a controlled way the radiation emission of a disturbed atmosphere. The radiation signals, created by an electron beam from a rocket-launched probe, would give information on disturbed atmospheric chemistry and physics."[70]

Another source states that "A major objective of the HAES/EXCEDE program is to determine the chemistry set that describes the behavior of the upper atmosphere after irradiation with a nuclear device."[71] How this would occur was briefly described in another report: "As these electrons and their secondaries are stopped in the atmosphere, they produce optical and infrared emissions which simulate, under well – controlled conditions, the results of energy deposition by charged particles and photons from nuclear explosions."[72]

Most of the atmospheric dosing experiments associated with EXCEDE in the 1970s were primarily developmental flights. An example is the November 19, 1976 launch of Talos Castor 651 92-1, which was described in the opening paragraph of this paper. The major objective of this flight was to test "the recovery system designed for use on large, rocket-borne, electron dosing and measurements payloads."[73] As indicated earlier, the electron guns were also being tested on this flight. These flights were also collecting important experimental data. According to Kay Baker, "[The early EXCEDE experiments] were sort of dual-nature you might say, developmental and experimental. . . . Each step you take . . . you get more sophisticated in your instrumentation, higher power on your electron beam, more controlled beam—and so all of those kind of fit into a pattern of going more and more sophisticated."[74]

Perhaps the most experimentally significant EXCEDE flight in this decade was EXCEDE II, which USU scientists and engineers launched on October 29, 1978, and then re-launched a year later on October 19, 1979. Unfortunately, the 1978 launch did not go well: "Although launch and flight of the vehicle were as planned . . . the door behind which all optical measuring devices were situated, failed to deploy." The 1979 launch was much more successful. All instrumentation performed as programmed and good data were recorded.[75]

The EXCEDE, ICECAP, and RBFWI projects provide examples of how space and atmospheric research at USU in the 1970s was influenced by national defense concerns during the Cold War. Studying natural and artificial auroras allowed researchers to continue collecting the kind of data that had been obtained by atmospheric nuclear tests before the 1962 Limited Test Ban Treaty. Additionally, Infrared research provided the data needed to devise early warning systems. Though IR research did not relate directly to BMEWS (the system of radar installations which was the early warning system in operation at the time), Kay Baker explains that IR research was applied to "some of the military satellites that are floating around now up there. . . . The primary function that we provided was not the instruments or the satellites themselves, but the background information that allowed them to then utilize those."[76]

Of course it should also be stressed that in addition to providing information for DoD early warning system designers, this research resulted in a great deal of scientific knowledge about auroras and the atmosphere in general. As Kay Baker claims, "from a science point of view, [the DoD funded research] allowed you to learn a lot about the aurora and the natural processes going on in the polar atmosphere." Nevertheless, this research ultimately owed its existence to military funds. Even without the Cold War, research of this type might at some point almost have been carried out; still, the funding and questions that prompted it would likely have been very different. Such was the case in the 1960s, and through the Strategic Defense Initiative of the 1980s, the Cold War would continue to influence space and upper-atmospheric research at USU.

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