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**PROGRESS REPORT ON AERONOMY
RESEARCH AT RICHLAND, WASHINGTON**

R. J. HOCH

JUNE 1968

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PROGRESS REPORT ON AERONOMY
RESEARCH AT RICHLAND, WASHINGTON

By
R. J. Hoch

Applied Physics and Electronics Department

June 1968

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PROGRESS REPORT ON AERONOMY
RESEARCH AT RICHLAND, WASHINGTON

R. J. Hoch

INTRODUCTION

This report covers activities in aeronomy research at Richland from July 1967 to April 1, 1968. The period has been a productive one in which we have begun to realize the results of the early work on experimental apparatus and facilities.

Among the main accomplishments of this 9-month period were: completion of the second meridian spectrograph and establishment of an observing program at the northern station in Banff, Alberta, Canada; completion of the laboratory and office facilities at the observatory on Rattlesnake Mountain; and acquisition and installation of the photometric apparatus from Boulder, Colorado.

We apparently won the race to get the photometric apparatus set up at Rattlesnake Mountain before solar activity increased to the point where the Stable Auroral Red arcs reappeared. In our first week of operation, we recorded the first definite occurrence of a SAR arc in four years. On that occasion, we combined our data with the records from the Fritz Peak, Colorado station to make the first direct measurement of SAR arc altitude. In the last few months we have also started analysis of the Banff-Rattlesnake two-station spectrographic data.

We are working on a tentative explanation of the SAR arcs in terms of world-wide motions of the ionosphere, and progress has been made on the design and procurement of what will be a very advanced photometric scanning system.

Disproportionately large amounts of time and effort are consumed by relatively routine tasks such as data

analysis, film processing, and trouble shooting. In this report, space and words will be allotted to various items more on the basis of probable interest than on the basis of man-hours involved.

DEVELOPMENT OF THE AERONOMY LABORATORY

On October 23, 1967, we described the then nearly completed facilities on Rattlesnake Mountain to the regional members of the American Geophysical Union at a meeting in Moscow, Idaho. The purpose of the presentation, encouraged by the local AEC, was to acquaint regional scientists with the site and to invite them to make use of the facilities for their related research. Establishment of the site was very well received at the meeting and in subsequent months because of the need for a station in the Pacific Northwest. The burden of mid-latitude coverage was found to rest more heavily on the Rattlesnake site than anticipated because the Rapid City South Dakota station, at our geomagnetic latitude, apparently could not be operated at this solar maximum.

Opening the site for cooperative use has worked out very well. For example, Dr. Bennett of nearby Central Washington State College has begun working with Dr. K. C. Clark of the University of Washington and with us on the development of an image intensifier-spectrograph system for high speed auroral spectroscopy. We tested a prototype of the device on a SAR arc at Rattlesnake on February 28, 1968 with very good results (Figure 1). This development is related to our eventual need for a high speed scanning system. Similarly, as a result of the presentation in October, Dr. Hessler and Dr. Kenney of the Boeing Scientific Laboratory are assisting us in the construction of a magnetometer to provide instantaneous information on geomagnetic field fluctuations.

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FIGURE 1. *K. C. Clark (left) and R. B. Bennett Adjusting a Prototype Spectrograph for Calibration Tests*

Technically, the development of facilities is outside the scope of the aeronomy research programs. However, these programs have entirely motivated development of the site because of the importance of facilities to research. Since the facilities are now suitably complete for full-time occupancy, it may be well to describe the place where the work is performed.

As we asserted at the outset, the site is favorably located for mid-latitude auroral studies. Figure 2 shows a statistical distribution of SAR-arc positions from the last solar maximum. It should be explained that, while Rapid City

is not operating now, Fritz Peak is. Results of observations to date bear out the favorable location. Of the six SAR arcs recorded so far, the Fritz Peak station has simultaneously been within observing range and had clear weather on only one occasion. Fritz Peak, by recording only 29 SAR arcs in 11 years, led us to regard the SAR arcs as relatively rare phenomena. More data is being collected at Rattlesnake than was anticipated.

FIGURE 2. Statistical Distribution of Position of SAR Arcs Based on About 500 Observations on 23 Nights from Rapid City, South Dakota

Winter weather at the site was better than expected on the basis of past records of cloud cover measured from the valley floor. The 3568-ft elevation would often put the peak above the inversion layer sometimes covering the rest of the basin. On approximately half the nights on which the valley floor was totally obscured, the sky was clear enough to permit observations at the site.

Stray light is low at the site and, as population spreads, such convenient dark observing sites become increasingly difficult to find. The Commission has decided to set aside one side of the mountain and the adjacent valley floor for a permanent ecology preserve (Project ALE, Arid Lands Ecology). There will be no lights there for the foreseeable future. Stray light from the other side of the mountain is also low because only open farm land is immediately adjacent, and the closest three towns are small and 20-25 miles away.

We have found that the few mercury lights now popular outdoors do not compromise the present research since the narrow pass band filters of the photometer exclude the mercury lines. We have learned to use the mercury lines on the spectrograms to our advantage in finding clouds and haze. For example, if an auroral emission is attenuated in some part of the sky, we look for a mercury line reflected from that part of the sky as an indication of cloud presence. The low lying dust of the desert locale is more bothersome than expected. The main problem is that the dust makes atmospheric attenuation of "external" light something other than the usual negative exponential function of air mass and, unfortunately, the situation appears to be rather variable. We can cope with the situation, however, by measuring the intensity of stars of known magnitude. These stars are automatically detected as photometric maps of the sky are made. The attenuation at a particular time can thus

be determined empirically. Rattlesnake Mountain (Figure 3) has the minor distinction of not having a single tree on it. Someone has suggested it may be the highest treeless mountain known.

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FIGURE 3. Rattlesnake Mountain

The buildings atop the mountain are owned and provided for our use by the U.S. Atomic Energy Commission. The local Commission has also handled reactivation and modification of the facilities to make them usable.

In the last year, interiors of the buildings shown in Figure 4 have been changed from abandoned (vermin ridden) former barracks to clean, well lighted offices and laboratories. Figures 5a and 5b are "before and after" photographs of part of

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FIGURE 4. *Aerial Photograph of Aeronomy Laboratory
Atop Rattlesnake Mountain*

the interior. General layout of the interior is shown in Figure 6. Floor area is about 5000 ft², with an office and lab space for about 10 men. Water is now pumped in from a nearby spring and the buildings have steam heat. Electric service brings about 40 kW power to the site and, of course, there is telephone service. Year around access is provided by a rather steep but paved and well maintained road. Visitor access is restricted to those appropriately badged and having official business.

The motivation for providing the several different workshops inside the building was primarily to allow the observer to make good use of his time when the weather or moonlight prevented observations. Secondly, the somewhat remote location of the site (about 20 miles from the main laboratories) requires the most needed equipment to be close at hand. A fairly self-contained laboratory is provided for visitors who may not have the run of the main laboratories.

The refurbishing consisted of painting, lighting, establishing electrical and water service, installing and removing some partitions, and moving in equipment and furniture. Sliding shutters were made for the insides of the windows to maintain darkness outside the building at night and to permit optical experiments to be performed inside during the day.

The University of Washington has installed a telescope near the building. This 16-in. diam Cassegrain reflector is shown in Figure 7. Visiting astronomers use the facilities we provide, and we plan to use the telescope for certain aspects of aeronomy research. The astronomers have provided atmospheric extinction data useful to our data analysis.

FIGURE 6. General Layout of Interior of Laboratory

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FIGURE 7. 16-in. diam Cassegrain Reflector Telescope

THE SPECTROGRAPHIC PROGRAM

An auroral spectrograph, housing, associated electronics, tools and other gear were loaded into a light aircraft on November 12, 1967 and taken to Banff, Alberta Canada (Figure 8). Light aircraft was determined the most economical means for transporting equipment and personnel to the northern site. However, crossing the Rockies in a light aircraft in fall weather proved quite an adventure. With the help of University of Calgary personnel, the equipment was transported from the landing strip at Banff to the top of 7200-ft high Sulphur Mountain where the University of Calgary had established a Cosmic Ray monitoring station.

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FIGURE 8. Unloading the Auroral Spectrograph in Banff, Alberta Canada (left to right R. J. Hoch; Peter Hof, University of Calgary; W. E. McKay, pilot)

We had made arrangements with Dean Brian Wilson, who established the station, and with Dr. Clifford Anger, both of Calgary, to install the equipment and to introduce Cosmic Ray station personnel to maintenance procedures, film retrieval, and film processing. We were hesitant to have undeveloped film sent to us across the border because of customs inspection problems. Aside from that, however, Dr. Anger and station personnel with backgrounds in auroral spectroscopy were interested in the data they helped us obtain.

Installation, alignment, and testing of the spectrograph was accomplished without delay and the instrument has been operating reliably since. Minor problems are corrected by competent Calgary personnel at the Cosmic Ray station. Figures 9 and 10 show, respectively, checkout of the instrument upon our arrival at the station, and Mr. John Porter who maintains the spectrograph, processes the film, and records cloud conditions for us.

Prior to establishing the Banff operation, we constructed a second spectrograph. We installed the newly constructed spectrograph at Rattlesnake and sent the original one to Banff. Although we had previously planned to send the new spectrograph to Banff, we finally decided to send the old one because of the likelihood of fewer "bugs." It had the smaller, nonmetallic housing preferred by the Cosmic Ray people and, since it was owned by the University of Washington, it could also be readily loaned across the Canadian border. Figure 11 shows the new spectrograph as it was being assembled at Rattlesnake. The large curved slits above the mirror are shaped to form a straight virtual image of the sky below the mirror. Figure 12 shows the completed new spectrograph in its housing on the roof of the Rattlesnake station. The larger

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FIGURE 9. *Checking Out the Spectrograph at the Cosmic Ray Station on Sulphur Mountain*

FIGURE 10. *John Porter and Friend at the Spectrograph Site*

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FIGURE 11. *Auroral Spectrograph During Assembly
at Rattlesnake (interior shutters on
lab windows shown in background)*

housing makes working with the new instrument more convenient since the operator can go inside for calibration or servicing. The window angles have been changed from the original design to eliminate the reflections causing problems with the older instrument. In addition, the camera drive mechanism was totally redesigned and the electronics simplified.

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FIGURE 12. *New Spectrograph Installation on Roof
of Laboratory at Rattlesnake*

Before taking the original spectrograph to Banff, both instruments were set up in a symmetrical arrangement inside the laboratory at Rattlesnake. A series of calibration tests were made with standard light sources to provide a permanent record

of the relative sensitivity of the two instruments for future reference. Their optical characteristics were virtually identical as would be expected.

We cannot yet identify with certainty a case in which both spectrographs recorded a SAR arc, although several SAR arcs have occurred since they were placed in operation. We did not have clear weather at both stations when a sufficiently intense arc occurred.

The two-station records are being analyzed in detail by the University of Washington staff. We had already made a quick survey of the two-station records at the Rattlesnake Laboratory and concluded that there were no simultaneous records of SAR arcs. It became apparent that the spectrographs could be greatly improved by increasing their sensitivities through the use of image intensifiers interposed between the camera and grating. The image intensifier mentioned in the preceding section was found to improve sensitivity about 100-fold.

Miss J. Virginia Lincoln, who publishes the IER-FS Solar Geophysical Data of the ESSA Research Laboratory in Boulder, Colorado, was interested in obtaining synoptic data on mid-latitude auroral records. We have discussed with her data regarding specific nights, and we are also cooperating with several others who, from time to time, request such information. We plan to begin routine reporting to Miss Lincoln and about a dozen other scientists in the near future.

THE PHOTOMETRIC PROGRAM

After deciding to operate the photometric scanning apparatus, we first had to cope with the logistics problem of moving several tons of equipment from Boulder, Colorado,

to the top of Rattlesnake Mountain. Most of the equipment was in, or could be put inside, a 35-ft van. An 8-ft diam by 18-ft tall steel silo also arrived by truck after various hinges and brackets had been cut off to meet interstate highway width regulations. A portable crane was brought up to the Rattlesnake Mountain site and, with it, the silo was set up on a pre-existing concrete pad. Riggers then fixed the silo to concrete anchors poured into holes made in the basalt. Everything was made very sturdy because of winds recorded as high as 137 mph at the site during late summer. Because of the wind, we decided to abandon the van and move all the electronics inside. The van was taken to the laboratories below and loaned to the atmospheric physics group.

Most of the equipment had not been operated before and some of it was not quite finished. We completed the electronics, modified the altazimuth mount to increase the height about 12 in., checked everything out, and began systematic observations about September 25, 1967.

Figures 13, 14, 15, and 16 show the several items of photometric equipment indicated by the captions.

A SAR arc occurred on September 28. A portion of the strip chart record, made while scanning 360° azimuth at three elevation angles, is shown in Figure 17. A brilliant auroral display simultaneously observed in the northern sky was described in a note by the observer as follows:

"Between the hours of 11 and 1 a.m. there was an auroral display that you wouldn't believe. Waves, sheets, and rays in constantly changing patterns. One interesting thing was the fact that I could see red waves whipping from the northern horizon up to about 30 to 40 degrees above the horizon. These

*FIGURE 13. Silo Housing the
Photometric Scanning Apparatus*

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*FIGURE 14. 35-ft Van Housing
Photometric Control and
Recording Equipment*

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FIGURE 15. Photometric Scanner Control and Recording Equipment (E. Wallace, relief observer)

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FIGURE 16. Adjusting Photometer on the Alt Azimuth Mount (left, E. Wallace; right, R. J. Hoch)

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red waves moved very fast, 1 or 2 per sec, above the general green diffuse glow. There were numbers of green curtains, slowly swinging back and forth. Bright spots and flashes, also green. Some very diffuse red on the north-northwest horizon. It is all recorded on the scan. The total range of brightness was slightly more than three decades."

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FIGURE 17. Strip Chart Record of SAR Arc

Direction of rotation and elevation angles are noted. Elevation was changing during intervals marked "E". The twin spikes occurring three times are the places where the SAR arc was detected.

The SAR arc itself was not visible. From our records of the event and the records of Marovich at Fritz Peak, a paper was prepared (Appendix A of this report) for publication and submitted to the Journal of Geophysical Research. The expected publication date of this report is July 1, 1968 in vol. 73.

The photometer is operated every moonless night that weather permits observation. In routine operation, we make photometric maps of the sky intensity at 4278 Å, 5577 Å, and 6300 Å. These wavelengths are, respectively, a band head of the first negative group of molecular nitrogen, the [$^1S \rightarrow ^1D$] transition of atomic oxygen, and the [$^1D \rightarrow ^3P$] transition of atomic oxygen. Presence of 4278 Å indicates a high energy excitation mechanism apparently typical of a polar aurora. The 5577 Å line is present both in the aurora and in the airglow chiefly at about 100 km, and the 6300 Å line is present in the polar aurora (usually at high altitudes) in the airglow and, of course, in the SAR arc. The airglow is essentially a permanent and stable feature of the night sky and the polar aurora, and SAR arcs, when they occur, are superposed on the airglow background radiation. On one occasion, while mapping a SAR arc with the photometer, we used the angular coordinates of the sky map to point a high-speed prototype spectrograph at two different regions of the sky. First, we directed the spectrograph toward a known SAR arc with an aurora behind it and, second, we pointed it toward a polar aurora region without a SAR arc. The geometry of the experiment is sketched in Figure 18, and densitometer traces of the spectrograms obtained are shown in Figures 19a and 19b. The SAR arc was not really visible, as Figure 18 may suggest. Even though the logarithmic intensity response of the film was not corrected on the prototype spectrograms shown here, one can see the 6300 Å

emission in the SAR arc region to be about three times more intense than in the polar aurora. To obtain the factor of three the fact that the weaker member of the doublet (the 6364 line) is always $1/3$ the intensity of the 6300 Å line is used. Then it is noted that the deflection of the pen for 6300 Å in the polar aurora is about the same as the deflection for 6364 Å in the SAR arc superposed on the aurora.

FIGURE 18. Geometry of a Special Spectrographic Observation of a SAR Arc

The spectrograms also show the general spectral composition of the sky, including mercury lines due to the presence of a light haze. These spectrograms were noisy because of the

FIGURE 19a. *Spectrum of the SAR Arc Superposed on a Polar Aurora*

FIGURE 19b. *Spectrum of the Sky in the Region of the Polar Aurora*

high photographic speed of the instrument. The much cleaner records of the meridian spectrographs (Figure 20) better illustrate spectral composition.

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FIGURE 20. Densitometer Tracing of Spectrogram of an Aurora Recorded by the Meridian Spectrograph at Rattlesnake

The intensity distribution of emissions over the whole sky at a particular wavelength are conveniently displayed on a circle map of the sky. Figure 21 shows the sky intensity of 6300 Å light in digital format. Figure 22 is the isophotal contour map worked out by hand from the digital map. We use three significant figures, however, at each point from tabular data printed out with the map. Data are truncated on the map to prevent crowding. The maps have been corrected for the

contribution of galactic and zodiacal light and for the main geometrical effects plus scattering and extinction by the atmosphere. These corrections are made automatically by a computer program written for the job.

FIGURE 21. Digital Map of Intensity of 6300 Å Light

FIGURE 22. *Isophotal Contour Map of 6300 Å Light
Corresponding to Digital Map of Figure 21*

These maps are fairly good representations of the sky if the observed phenomena are almost stable. They do not show much detail and, if the auroral forms are moving, the maps are badly distorted. This conclusion is illustrated by Figures 23 and 24. Figure 23 shows the smoothed motion of an arc southward throughout the night. Figure 24 shows the fit of two-station observations for two cases; (1) when the arc is moving,

and (2) when it is nearly stationary. The observing equipment at the two stations is similar and neither observing arrangement can resolve the position well when the arc is moving.

FIGURE 23. *Northward Displacement of East Tip of Arc Relative to Fritz Peak (greatly averaged and smoothed)*

At this time, there is no general agreement on overall excitation mechanism for the auroras, either the polar auroras or the SAR arcs. From the outset of this program, our attention has been focused mainly on the SAR arcs because their stability, apparent spectral purity, and discrete locale made them attractive for study. But Dr. Roach has pointed out that the final explanation of even these arcs may require consideration of the world-wide picture of airglow and auroral activity,

as well as the gross motion of the ionosphere. He suggests that the high, red A-type aurora of the polar regions, the SAR arcs at mid-latitudes, and the red tropical airglow enhancement near the equator may be closely related phenomena. The idea is that the ionosphere, like the gaseous atmosphere, is driven by thermal tides due to solar heating as the earth revolves. The tidal motions give rise to large scale current systems by virtue of the forces on the charges due to their motion through the magnetic field. It is suggested that such systematic variations of ionospheric density and drift give rise to the usual tropical airglow and type A-red auroras. In the case of a compressed magnetosphere during a magnetic storm, some "abnormal" system might develop in the mid-latitude region to cause the SAR arcs.

FIGURE 24. *Position of the Brightest Region as Observed from Two Stations*

As we fit specific information into this qualitative picture, unusual motions of the ionosphere at mid-latitudes during magnetic storms indeed are found. The virtual height of the ionosphere appears to increase radically, and there is a strong upward motion of ionization to the 400 km region where the SAR arcs occur. Conversely, the same mid-latitude region appears to be remarkably quiet and motionless during normal conditions.

It is suggested the atomic oxygen emission [$^1D \rightarrow ^3P$] 6300 Å in the upper atmosphere is the result of two separate and distinct mechanisms. In the tropics, the predominant mechanism is the dissociative recombination of the oxygen molecular ion and an electron

The reaction is exothermic (6.96 eV) and can result in excitation of the oxygen atom to either or both of the levels 1S or 1D with resulting emission of [$^1D \rightarrow ^3P$] 6300 Å and/or [$^1S \rightarrow ^1D$] 5577 Å. In mid and high latitudes, dissociative recombination is thought to be the principal mechanism of excitation during times of geomagnetic quiet. However, during times of geomagnetic disturbance when electromagnetic drifts cause a vigorous uprush of ionization to heights where the excited (2D) oxygen ion exchanges energy with the oxygen atom in the ground state, dissociative recombination is regarded as of secondary importance. The latter is raised to the 1D state

For the so-called type-A red auroral displays of the polar regions, there is the alternate possibility that the excitation is due to a quick increase in temperature, particularly that of the electrons followed by efficient

moderation of the higher temperature electrons by nitrogen molecules. This thermal type reaction remains a strong candidate for the SAR arc mechanism, the only reasonable one (we thought) prior to noting the $O^+ (^2D) + O (^3P)$ possibility suggested by Dr. Mahadaven of Douglas Aircraft Advanced Research Laboratory. The main question with the thermal reaction is how the 1S level (4 eV), which sets up the [$^1S \rightarrow ^1D$] transition, could remain unexcited inasmuch as the 5577 Å radiation of this transition is not seen. The increase in temperature of the electrons themselves could be due to magnetohydrodynamic waves. We have underway two approaches to investigate the "thermal mechanism" but, before discussing them, we would like to conclude description of our work on the world-wide model.

Two aspects to the overall problem are (1) to see if the overall motions of the ionosphere really correlate with the magnetically aligned emitting regions in the polar, mid-latitude, and tropical zones, and (2) to find the correct reactants for the high altitude 6300 [$^1D \rightarrow ^3P$] in the mid-latitude and polar regions. The correlation found so far for ionospheric drifts is good, but our data are not nearly extensive enough. The only mapping of ionospheric drift vectors available was that of Maeda (1959),* which was highly averaged data over years lower in magnetic activity than we presently have. We are currently working out up-to-date maps for the ionosphere and, so far, the tentative conclusions hold. We are also trying to arrange an ionosonde (University of Washington owned), and are installing a magnetometer

* Hiroshi Maeda. "Horizontal Winds and Ionization Drifts in the Ionosphere," Report of Ionosphere and Space Research in Japan. Vol. XIII, no. 1, 1959.

(loaned) at the Rattlesnake site. We had to redirect attention somewhat from earlier planning as these ideas evolved, but the explanation of the arcs is the real goal and these ideas appear both promising and worthwhile pursuing.

Because the relative population of the first two excited states of oxygen is strongly temperature-dependent via $kT \ln \exp (E_2 - E_1)/kT$, we cannot exclude a thermal excitation mechanism simply because 5577 Å radiation is very weak. If the SAR arcs are caused by thermal excitation, that is, if electrons heat the atomic oxygen, then we would like to know three things in addition to the concentrations of atoms and charged particles. These are the energy spectrum of the electrons, the energy-dependent cross section for the electron-oxygen excitation process, and the temperature of the atomic oxygen. The first one, the energy spectrum of the electrons, while not easily measured, can be reasonably assumed on the basis of the origin we assume for the electron energies. However, some progress can be made on the energy-dependent cross section for the electron-oxygen excitation and the temperature of the atomic oxygen.

It is relatively straightforward to measure the temperature of the oxygen by measuring the Doppler broadening of the 6300 Å emission line. The natural line width is inversely proportional to the lifetime of the state or virtually nil in this largely forbidden transition ($\tau \approx 117$ sec). We propose to measure the line width by fixing a Michelson interferometer to the back of the 16-in. telescope (Figure 7) and pointing the telescope at a SAR arc as we determine the angular coordinates of the arc with the photometer. The output of the interferometer, as the optical path length of one leg is varied, will be Fourier-analyzed to determine the line profile and, hence, the gas temperature.

Preferential excitation of only the lowest excited state of atomic oxygen might also be due to a resonance in the oxygen cross section in the 2 eV electron energy range rather than to an unusual energy spectrum of the electrons. Although the cross section is difficult to determine experimentally, calculation appears possible. Various calculations of the cross section by others have made simplifying assumptions which would suppress indications of a resonance. Specifically, one must keep exchange terms (in the matrix elements) which arise when the interaction is calculated.

The interferometer experiment for temperature determination is planned for next year, and the calculation of the cross section has already been started. Some funds have been set aside to cover costs of computer runs for the cross section calculation this coming year.

AUTOMATION OF PHOTOMETRIC APPARATUS

Authorization to proceed on this aspect of the work was received just two weeks prior to the preparation of this report. We are in the process of writing specifications for hardware to be purchased. A block diagram of the new system is shown in Figure 25. A detailed description will not be given here. One important point is that we plan to construct the new control and recording apparatus parallel to the existing equipment to insure only minimal interruption to the observational program when new equipment is put into operation.

PLANNING

The short term goal of the research program is to explain or contribute to the explanation of the SAR arcs. We now see that an adequate explanation may require, on the one hand, consideration of world-wide ionospheric behavior

FIGURE 25. Block Diagram of Automated System

and, on the other hand, consideration of atom-electron collision cross sections. Neither of these aspects was specifically considered at the outset, and these examples have taught us the importance of breadth and flexibility in the research. We feel that we should try to develop a balanced program consisting of roughly equal efforts in observations, analytical (theoretical) work, and laboratory experiments. At the moment, it is clear that the research is heavily biased toward the first of these (observations) and painfully short of the second (analytical work). This is not to say that a good deal of time is not spent "analyzing" the data output. The inordinate amounts of time required to reduce data, however, are not productive in terms of explaining things or exploring new ideas and such time should, in our view, be counted as observations. A major step toward improving the situation has been taken in the recent authorization of equipment funds

to automate the observing equipment. Completion of that task, now just starting, should save almost a man-year per year and, at the same time, greatly improve spatial and temporal resolution of the sky maps. Eventually, freed manpower will be redirected to analytical and experimental work. Experiments in the laboratory such as testing, checking, and calibrating of observing equipment are carried out now. Really envisioned here, however, are experimental determination of, for example, the electron cross section of atomic oxygen, or perhaps the laboratory duplication of the $O_2^+ (^2D) + O (^3P)$ reaction previously described. Such experiments, by present day physics standards, have the advantage of requiring rather low-energy incident particles. Consequently, the equipment required, though not of negligible expense, will consist of vacuum apparatus, photomultipliers, and other fairly standard items costing a few tens of thousands of dollars in the long run, but short of the \$100,000 level. We have found a virtual gold mine of equipment in government excess and, with the least bit of ingenuity, this equipment can be adapted to many of our needs at very little cost to the program. As an example, we are in the process of setting up an excessed screen room made entirely of copper down to the last screw and nut. This screen room will house our coil magnetometer and shield it from spurious electromagnetic radiation but it shouldn't screen out the very slowly varying geomagnetic field. The total cost of the magnetometer to the project will be only a few hundred dollars, but the field variation data to be obtained, together with ionograms, will be very useful for calculating ionospheric drifts. Our plans for equipment include continued utilization of such available apparatus when possible.

Because of the high interest apparent in our line of research at these laboratories, we find that theoreticians

and experimentalists in physics are anxious to help us on a fractional time basis. Therefore, theoretical or experimental work at whatever rate is merited by program progress and allowed by fiscal limitations can be developed.

We have found that informal presentations and discussions of our work with the rest of the physics staff of the laboratories have been well received, and the exchange of ideas involved seems to be of mutual benefit. We plan to continue these presentations as the opportunities arise.

The preceding paragraphs outline our general plans. Our specific plans are to:

- Automate the photometric observations and improve the resolution of the scanning equipment
- Redirect whatever manpower can be saved through automating into analysis
- Speed up the spectrographs by installing image intensifiers
- Make the electron-oxygen cross section calculation
- Set up a magnetometer and arrange ionosonde tests
- Continue development of the world-wide picture of ionospheric motion
- Attempt a temperature determination of the temperature of oxygen gas via the 6300 Å line profile
- Eventually begin laboratory experiments on atomic collision processes.

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APPENDIX A

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REAPPEARANCE OF A STABLE AURORAL
RED ARC AT MID-LATITUDES

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REAPPEARANCE OF A STABLE AURORAL
RED ARC AT MID-LATITUDES

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ABSTRACT

A Stable Auroral Red (SAR) arc was recorded the night of 28/29 September from stations at Fritz Peak, Colorado, and Richland, Washington. The first direct determination of position and altitude of a SAR arc was accomplished by triangulation from these two stations. The appearance of this arc marks the definite reoccurrence of this phenomenon after an apparent absence of four years. The arc, occurring southward of an intense auroral display, was aligned parallel to lines of constant L. Average intensity of [OI] 6300 Å emission in the brightest part of the arc was approximately 150 R. Altitude of the brightest region was determined, from angular coordinates at the two stations, to be 400 km at 0745 UT. A typical width across the narrow dimension of the arc was 160 km between half maximum intensity values. A sector of the arc almost 4200 km long was simultaneously within the combined range of the two stations. The arc occurred during a period of high magnetic activity and, though a comparably intense aurora borealis occurred the night before (27/28 September), no SAR arc was observed from either station.

APPENDIX A

REAPPEARANCE OF A STABLE AURORAL
RED ARC AT MID-LATITUDESR. J. Hoch, E. Marovich,
and K. C. ClarkBACKGROUND

During the decline of the last solar maximum, numerous photometric observations were reported of a stable arc-like emission of [OI] 6300-6364 Å at mid-latitudes. D. Barbier⁽¹⁾ identified the arcs as phenomena peculiar to mid-latitude regions and distinct from polar zone auroras. Roach and Roach⁽²⁾ have summarized results of observations from 1957 through 1963, and Marovich⁽³⁾ compiled occurrences at Fritz Peak, Colorado, for the period 1955 through 1965. These results indicated that the emission appeared to be exclusively 6300-6364 Å OI[³P-¹D]. The arcs, called Stable Auroral Red (SAR) arcs, were aligned parallel to lines of constant L. The emitting region was distributed over the 300-700 km altitude range and was brightest in the 400 km region. North-south width of an arc was characteristically several hundred km, and the total length of a typical arc may well have been such that the arc spanned the entire dark side of the earth.

The arcs, usually persisting from dusk until dawn, exhibited good stability. A slow southward drift very often was observed.

Occurrence of the SAR arc correlated strongly with periods of high geomagnetic activity. Frequency of occurrence of the arcs decreased from about 12 per year, reported during peak solar and geomagnetic activity in 1957 and 1958, to five in 1961. Following a 24-month

period during which no SAR arcs were reported to have been observed, a single arc was recorded by Marovich on 22/23 September, 1963. The occurrences then appeared to cease.

It seemed reasonable to expect the arcs to reappear at mid-latitudes when magnetic activity increased during the approach of the solar maximum.

In anticipation of the reappearance, an observing station was set up in Richland, Washington (lat $46^{\circ} 24' N$, long $119^{\circ} 55' W$, $L = 2.7$) which is in the middle of the zone where the SAR arcs previously occurred ($L = 2$ to $L = 4$). From this site, triangulation on a SAR arc could be accomplished in cooperation with the established Fritz Peak, Colorado station (lat $39^{\circ} 54' N$, long $105^{\circ} 29' W$). Geomagnetic latitude and longitude are $52.2^{\circ} N$, $299.0^{\circ} E$ for Richland, and $48.7^{\circ} N$, $316.2^{\circ} E$ for Fritz Peak.

On 28/29 September, 1967, a SAR arc appeared and the measurements reported here combined data from the two stations. The occurrence of a SAR arc on the night of 28/29 September, 1967 marks the definite reappearance of the phenomenon after an apparent absence of 4 years. An earlier SAR arc may well have occurred on 2/3 May, 1967, according to almucantar scans of $6300 \text{ \AA}$ intensity made by Marovich at Fritz Peak, but records of 28/29 September are more complete and permit unambiguous identification of the reappearance.

OBSERVATIONS

Photoelectric scanning photometers operating at Fritz Peak and Richland produced simultaneous records of a SAR arc which occurred the night of 28/29 September, 1967. At each station, a record of incident intensity of $6300 \text{ \AA}$ radiation as a function of azimuth and elevation angle was recorded. These stations are separated by 1480 km, and an

auroral form 400 km above one station is seen at almost 10 degrees elevation from the other. Thus, a relatively unambiguous determination may be made of the position of an emitting region simultaneously within the lines of sight of both stations.

The position of the maximum intensity region of the 28/29 September SAR arc at 0745 UT is shown in Figure A-1. Average altitude of the sector within the line of sight of both stations was determined to be 400 km.

The altitude during a one-hour interval when the arc remained relatively motionless was determined by plotting the position of the arc as recorded from both stations for a number of assumed altitudes. The plots of the arc from the two stations were found to coincide in the region of mutual observation at the assumed altitude of 400 km. Uncertainty in the altitude determination was estimated to be about 30 km because of the diffuse distribution of the emitting region.

Since only angular coordinates were available on extreme sectors of the arc recorded from only one or the other of the stations, the altitude of these end sectors could not be determined directly. For purposes of mapping, it was assumed the end sectors were at the same altitude as the average for the middle sector. The overall curvature suggests this assumption to be reasonable. Total length of the sector of the arc covered by these combined records is 4170 km.

As shown in Figure A-1, the SAR arc was approximately parallel to lines of constant L. The latitude of the arc changed during the night, as described in the following, but rough alignment with lines of constant L was maintained.

FIGURE A-1. Position of the SAR Arc at 0745 UT
(2345 PST) September 29, 1967

Coincidence of best lines through the measured points in region between the Fritz Peak (FP) and Richland (R) stations indicates the 400-km altitude is correct. Northernmost (0306 UT) and southernmost (1050 UT) recorded positions of the arc are shown as well as reference lines of constant L and the 50° geo-magnetic parallel (GP). The map is undistorted along geographic latitude 44° N.

During the night the arc moved southward across the zenith of the Richland station at 0645 UT (2245 PST) and passed over Fritz Peak at 0940 UT. At 1050 UT, the arc reached its most southerly position when it passed approximately 2° south of the Fritz Peak zenith. It then reversed direction and, by 1125 UT, drifted northward about 100 km at which time sunrise precluded further observation. The altitude during the time when the arc was drifting rapidly southward could not be reliably determined from the mutual observations because motions of the arc during the 5-min interval required to complete a sky map acted to compromise resolution of position. The southward drift is illustrated by the sequence of arc positions shown in Figure A-2. The described drift and alignment depended only slightly on arc altitude, taken to be constant at 400 km in the analysis.

All sky maps of the intensity of $5577 \text{ \AA}$ light, recorded from Fritz Peak when the SAR arc was present, showed no arc-like structure in the $5577 \text{ \AA}$ emission in the region of the SAR arc. Meridian spectrograms made at the Richland station provided qualitative agreement that the SAR arc was predominantly the $6300\text{-}6364 \text{ \AA}$ emission of neutral atomic oxygen.

Average intensity was about 150 R in the brightest region of the arc. At any given time, intensity along the length of the arc was nonuniform, varying by about a factor of two. There were also sluggish temporal variations of about the same magnitude, apparently not correlated from place to place along the arc. Unobserved faint cloud patches possibly could have compromised observations of intensity. The maximum intensity recorded was 300 R in one bright region of the arc at 0745 UT. Width of the arc measured in the north-south sense was determined to have been approximately 160 km between half-maximum intensity regions.

FIGURE A-2. SAR Arc Southward Drift Illustrated by Positions at One-Hour Intervals as Observed from Richland Station

The SAR arc occurred during a time of increased magnetic activity as shown in Figure A-3. There was an intense poleward auroral display all during the night the SAR arc was recorded. There was also a poleward auroral display the night before (27/28 September). No SAR arc appeared to accompany the 27/28 September display though it was as intense as the poleward display of the night of 28/29 September.

FIGURE A-3. Daily and Three-Hour Planetary Magnetic Indices for Several Days Near Time of SAR Arc Occurrence

(Data from IER-FB Solar Geophysical Data of ESSA Laboratory, Issued November-December, 1967.)

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