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APPLICATION OF ELECTRO-OPTICS TO AURORAL STUDIES - PHASE II

J.E. Anderson

General Electric Company
Research and Development Center
Schenectady, New York

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Contract No. AF19(628)-2366
Project No.7661
Task No. 766101

Final Report (Phase II)
Period Covered: November 1963 - November 1965
December 1965

Prepared
for

AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
OFFICE OF AEROSPACE RESEARCH
UNITED STATES AIR FORCE
BEDFORD, MASSACHUSETTS

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ABSTRACT

During 1964-65 a continuing investigation was performed to examine the feasibility of obtaining information on the time-changing characteristics of the aurora and night air glow by low-light level image orthicons at the Radio-Optical Observatory of the General Electric Company's Research & Development Center in Schenectady, New York. Although no auroras were detected during this interim period, wavelength and intensity calibrations on a spectrograph of special design using the image orthicon detector were accomplished with spectral lamps and night air glow emissions. Included photographs of night air glow demonstrate that the image orthicon is at least 1000 times faster than photographic film when detecting weak "point" or "line" sources under high contrast conditions. Twenty photoelectrons are sufficient to record a spectral line. Sensitivity calibrations were also performed on a 16" f/20 telescope, where the North Polar Sequence of Stars provided a standard calibrated star field. Within 10 seconds, 18th magnitude stars were detected.

Further analysis is given on the data recorded during the September 1963 aurora and initially reported in the Final Report of Phase I, 1963 - AFCRL 64-209.

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1.0 INTRODUCTION

This document entitled "Application of Electro-Optics to Auroral Studies — Phase II" is the final report covering an auroral study supported through Mr. T. P. Markham by the Air Force Cambridge Research Laboratories, Office of Aerospace Research, USAF, under contract AF19(628)-2366, Project No. 7661 with the General Electric Company. Within the General Electric Company, the work was sponsored by the Heavy Military Electronics Department, Syracuse, New York and was carried out by the General Electric Research & Development Center, Schenectady, New York.

This report describes the experiments and equipment designs that have resulted during the interim period of this contract since the final report of Phase I[1].

Included are the results of a further analysis of the spectra taken during the September 1963 aurora, a discussion of the night air glow photographs, a critique on an advance image orthicon spectrograph design, and a sensitivity calibration on the image orthicon using the North Polar Sequence of stars, along with a 16" telescope, as a standard point light source.

2.0 WORK OBJECTIVES

The objective of the study as outlined in the Statement of Work is as follows:

"The Contractor shall supply the necessary personnel, facilities, services, and materials to accomplish the following:

1) To utilize an image orthicon and auroral spectrograph for studies of aurora and night air glow spectroscopy and attempt to obtain time resolution of changing features.

2) To utilize an image orthicon and filters for real time auroral photography to cover the visual region and near UV and IR in order to obtain information on the faster auroral motions; and also to obtain data as the brightness of the aurora drops below the visual level."

3.0 SUMMARY AND CONCLUSIONS

According to Drs. Gartlein and Sprague of the IGY World Data Center, Cornell University, a film such as 103A-F requires exposures on the order of one hour to detect night air glow spectra. In fact, night air glow detection on a 30-minute exposure with a f/0.7 optical system is very good. Comparisons of these film detected spectra with those of 1 to 5 second duration on General Electric's f/1.5 grating or Cornell's prism image orthicon system are quite comparable. The equivalent image quality with longer integration periods is degraded only because of dynamic range limitations in the image orthicon tube. This data indicates that the image orthicon is at least 1000 times more sensitive than film when used as a detector on a slit spectrograph operating against spectral sources with intensities as weak as 15 Rayleighs and high contrast.

Unfortunately, neither one of our image orthicon systems have produced significant publishable data to date, primarily because of weather limitations. As an indication, bright stars were visible at night in the Schenectady area only on the average of one night per month during the period of 1 January 1965 to the end of May 1965. Therefore, any attempt to detect night air glow on a night-to-night basis was impossible, and even within the period of one night haze presented a difficult problem. Needless to say, no aurora was visible during these times. As a result, the entire data accumulated during the study period consists of approximately 100 auroral spectra taken in September 1963 with relatively crude equipment, and assorted photos of night air glow spectra from various intervening

nights with and without haze present.

During the last few years, cloud formation and thick haze has seemed to be the rule in the Schenectady area at night; perhaps because of its windward position with respect to the Berkshire and Green Mountains. However, inquiries to others have produced the consensus that optical observation has recently been poor all over the world.

Although the observational results have been disappointing, the auroral study has resulted in the development of image orthicon techniques and calibration procedures, as well as discovering those spectrograph parameters to be optimized in an image orthicon-spectrographic instrument. The development equipment has resulted in a design capable of the high time resolution required to determine the intensity variations of night air glow and aurora spectra. Therefore, the time delays occuring between various emissions may be observed for a more complete understanding of the chemical and electrical phenomena of the upper atmosphere.

In the application of image orthicons to auroral spectroscopy as well as astronomy or space surveillance, sensitivity information on the basic detector characteristics are desired. Photographic investigations with a General Electric GL-7967 image orthicon on a 16-inch telescope demonstrate that under high contrast conditions, 200 photons produce a detectable point source signal. Calibration photographs taken at Schenectady, New York on the North Polar Sequence of stars show that 16th magnitude may be detected within one second of time under quarter moon conditions and 18.5th magnitude within ten seconds. The photos reproduced in this report exceed a 30 second exposure so that star identification is conclusive. System tests at f/4 and f/19 include the results of a 1.5° and a 11x16 minute field of view.

4.0 DESCRIPTION OF THE INSTRUMENTATION

A discussion of the general facilities and equipment, which is given in the December 1963 Final Report[1], adequately covers the General Electric Radio-Optical Observatory at Schenectady, New York along with a detailed summary of associated reports and memos that have been issued. These concern work accomplished with our 30-foot reflector antenna (which presently is a solid surface) along with the VLF to 2 Gc receiving equipment, as well as optical successes when using the 12" or 16" telescopes. Hence, only the improved instrumentation directly involved with this auroral study will be reviewed.

4.1 Photometer

The Radio-Optical Observatory developed a photometer for the purpose of obtaining surveillance calibration data that will be useful with the image orthicon. During the past year, extensive stellar photometry has been pursued using Johnson's UBV standard optical filters and known magnitude stars to calibrate sources of unknown magnitude. The photometer which is positioned on the 16" Boller & Chivens telescope also provides a means for an accurate intensity calibration of the spectral lines that will be simultaneously viewed on the auroral spectrograph with the image orthicon system.

Presently, the following filters are being used in calibration tests with the photometer:

i) Standard Johnson UBV filters

a) V - Corning No. 3384

b) B - Corning No. 5030 - Schott GG13

c) U - Corning No. 9863

ii) 100Å Bandwidth Auroral Filters

a) 3194Å - N_2^+

b) 4709Å - N_2^+

c) 5577Å - OI

d) 6300Å - OI

e) 6563Å - H_α

iii) Various 2" x 2" wideband optical filters.

The photometer design is a variation of the conventional approach. First, the alignment eyepiece is behind the aperture plate. This design was chosen to provide a simpler alignment procedure. Instead of a fixed aperture, a calibrated iris with a micrometer adjustment is used. For alignment, the eyepiece with a diagonal mirror and double crosshairs is lowered so that the aperture of the iris is viewed; with the iris full open, the field of view is approximately 3 minutes of arc, sufficient to locate a desired star or other object of interest which may then be centered in the aperture. In turn, the aperture of the calibrated iris may be reduced to any desired area with a field of view between 0.10 second of arc to 3 minutes of arc.

Secondly, the eyepiece is equipped with a full silvered and a half-silvered diagonal mirror so that a choice exists for raising the eyepiece assembly from behind the iris when the guide telescope is used for tracking, or the half-silvered mirror assembly may be left in place so that all guiding can be accomplished through the main telescope. If the disadvantage of an ultraviolet sensitivity loss because of the half-silvered glass attenuation factor is not objectionable then this last method insures accurate tracking and visual inspection of the target's characteristics.

Each of the manually operated filter wheels has 10 positions using 3/4

inch diameter filters. In addition a special slide holder for standard 2" by 2" filters may be positioned ahead of the aperture to allow for versatility.

The photomultiplier is housed in an American Dynamics Corporation Model TE-102 thermoelectric cooled refrigerated chamber that is capable of cooling to -30°C below ambient temperature. This degree of cooling was found to reduce the background noise of an EMI 9558 photomultiplier so that an initial S/N of 2 was increased by an order of magnitude. When dry ice was used to produce a cooler ambient temperature for the refrigerated chamber the further cooling did not produce any significant decrease in the photomultiplier noise. The face plate of the photomultiplier cooler and the Fabry field lens are made of quartz to permit ultraviolet investigations.

4.2 Image Orthicon Spectrograph

During the period of December 1962 through February 1965, experiments were performed using the spectrograph borrowed from Dr. C. Gartlein of Cornell University. The use of an image orthicon as a detector with this grating spectrograph of the conventional design exhibited limitations. In particular the usable aspect ratio of an image orthicon detector surface is 3:4 while that of the spectrograph exceeds 50:1. Thus with any optical system speed and given spectrum the resolution with a conventional grating spectrograph is poor and only a small region of the active photocathode surface of the image orthicon detector is effectively utilized. The use of this equipment did provide insight as to how to optimize the design, and an image orthicon spectrograph of superior design was built in June 1965. This equipment is described in an article submitted for publication to the Review of Scientific Instruments and included in this report as Appendix A. This special grating

spectrograph separates the 3800Å to 8000Å spectrum into three sections in such a manner that the three sections of spectra are imaged on the image orthicon with increased resolution and spectrum coverage. The three slit spectrograph design uses a 92 cm f/9 collimator lens, a 15.3 cm f/1.5 camera lens and one of two gratings: a 76 x 65 mm ruled area at 2160 grooves/mm, or a 100 x 100 mm ruled at 600 grooves/mm.

The spectrograph equipment has been automated so that on clear nights the time changing spectral characteristics of night air glow and/or aurora may be continuously recorded on 35 mm tri-X film along with the exact time at an exposure rate of one readout every 1 to 20 seconds depending on the desired integration period set on image orthicon readout controls.

4.3 Image Orthicon Camera

The image orthicon system is a special design of the Research & Development Center specifically directed towards the investigation of astronomical applications. The image orthicon tube, General Electric model GL-7967, has an S-20 extended red response photocathode and a magnesium oxide target for maximum sensitivity. Independent voltages and controls regulate the various grid potentials to at least 0.1%; thus providing a minimum of electronic interference as well as a variety of operational modes, which include provisions for target integration, multiple frame readout, microsecond exposures, and clock synchronization to within microseconds. The resultant stability permits a night-to-night duplication of results for identical illumination conditions. The single frame readout is a standard 1/30 second, 525 line non-interlaced scan. Since most applications use only a single frame readout after an integration period, particular emphasis was placed on the low noise preamplifier and amplifier circuits so that transients would not degrade the picture

quality. The measurements on the amplifier indicate a 4 db noise figure and a bandwidth of 15 Hz to 9.8 MHz at the 3 db points, when corrected to compensate for the estimated 15 pf of shunt anode capacitance across the 50 kilo-ohm preamp input resistance. All video signals are transmitted through 75 ohm coaxial cables having matched terminations on each end. Two 20 cm monitors with a blue phosphor P-11 response are used to obtain photographs with a 35 mm synchronized data camera or a 4" x 5" Speed Graphic camera.

5.0 RESULTS

During the interim period no visual auroras were observed at the Radio-Optical Observatory with the equipment. Fortunately in September 1963, auroral spectra was recorded as reported in the Final Report 1963[1], and the results of a further analysis of that data is included here. Data with the three-slit spectrograph consists of night air glow spectra taken on several nights during the fall of 1965. Although the recorded observational data has been meager because of the weather limitations, the calibration data and initial results demonstrate the potential of the image orthicon when used as a detector of weak spectral lines.

5.1 Auroral Spectra - September 1963

Following the successful real time filming of a flaming aurora with an image orthicon camera, as reported to the American Astronomical Society's 107th meeting in December 1960,[2] an auroral spectrograph was borrowed from Dr. C. Gartlein of Cornell University for the purpose of experimental investigations of image orthicon techniques to auroral and night air glow spectroscopy.

On the evenings of September 22-23 and 24-25, 1963, spectra of an aurora visible at Schenectady, New York were obtained on Polaroid film with an image

orthicon spectrograph. The primary purpose at the time was to work out the techniques for obtaining time resolution on the changing features of aurora, and for night air glow spectroscopy. This initial work was reported in the Final Report of Phase I, December 1963. The results with further analysis of the data in 1964 are discussed below. At the time, the equipment was not calibrated because of its experimental nature so that the intensity measurements are approximate and relative; nor were the spectra obtained at fixed intervals in time. However, the preliminary results are of interest because of the short exposures used -- about 10 seconds, and the noted relative amplitude changes between the various spectral lines that were observed, and because no other visible auroras were detected in Schenectady since this first success.

On the night of 22 September 1963, visual records and scattered photographs of a homogeneous band from 9:00 PM EDST to 10:00 PM show that the intensity of the lines increased fairly uniformly. During this time no relative change was observed between the 6300-6365 doublet of OI, or the 5577 line of OI. However, the lines 5678 and 5002 of NII began with the 5678 line stronger, but after about 9:30 the 5002 line became stronger. The exact time of the change over is difficult to give since these lines were both quite weak from 9:20 to 9:40. After 9:40 the 5002 line was quite strong.

The 3914 and 4278 lines (N_2^+) strenghtened uniformly during this period apparently not weakening as did the NII lines.

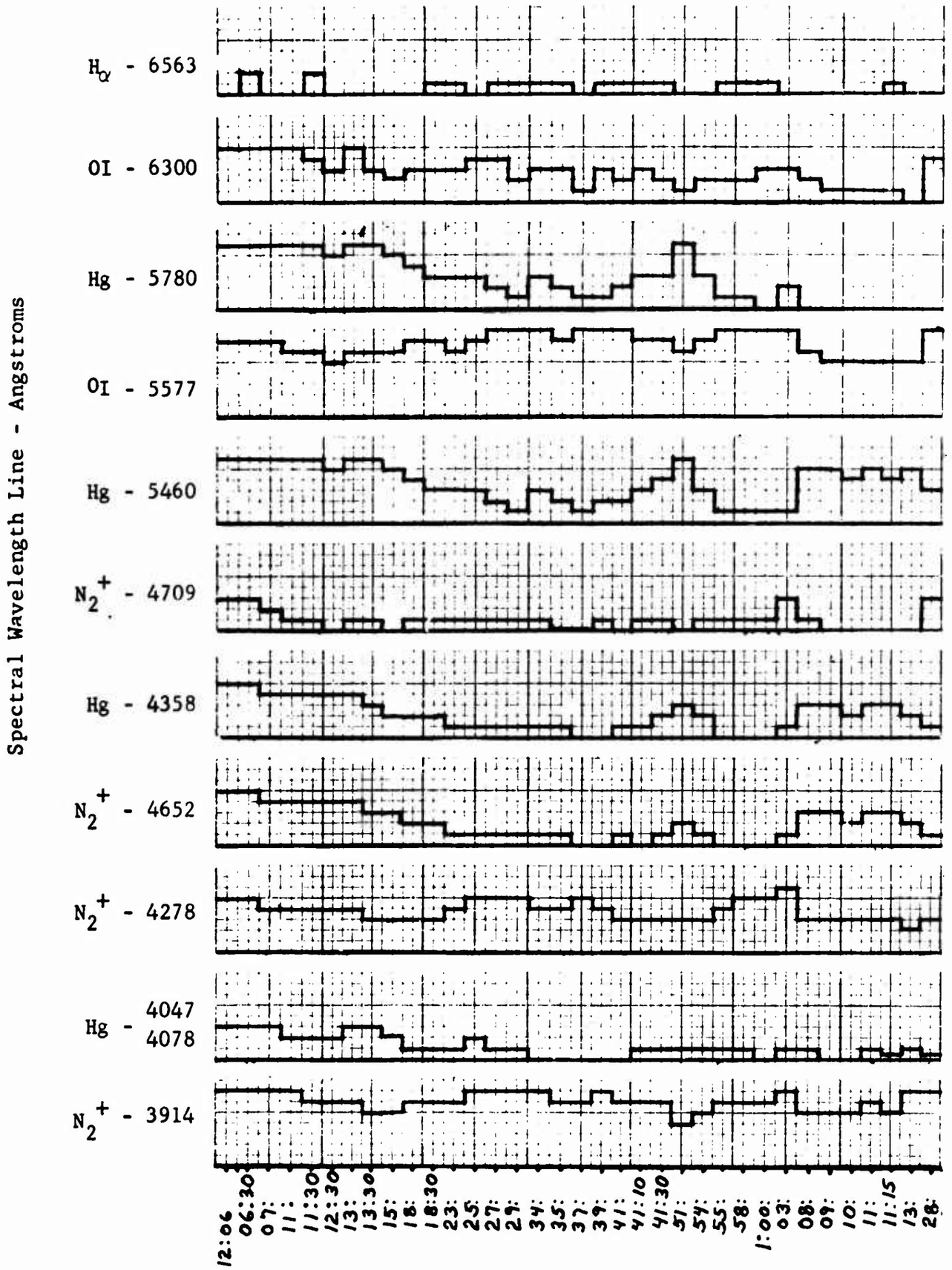
About 9:40 rays began building up and the aurora brightened at 9:44-H_β appeared weakly, at 9:48 it was easily detectable, and was fading at 9:48. At 9:51 it was gone. At 10:12 H_β appeared again, at this time the aurora was a bright diffuse glow.

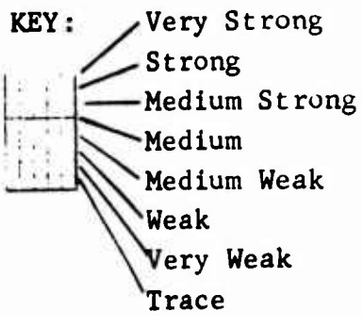
After 11:00 PM EDST to 2:00 AM, 45 excellent measurable spectra were obtained on Polaroid film with integration on the image orthicon target of approximately 10 second duration, one frame readout per film exposure, randomly taken with a mean rate of about one every five minutes. Figure 1 shows how the relative intensity of eleven spectral lines changed within one period of time. Particularly note that the time scale is not linear, for in some instances two or three photographs were taken within a one minute period. Also, the amplitudes have not been corrected for the S-20 response of the image orthicon photocathode.

The intensity level was broken up into the following eight measurable steps:

- Very strong - saturation of the image orthicon
- Strong
- Medium Strong
- Medium
- Medium weak
- Weak
- Very weak
- Trace - only detected because of apriori knowledged that a line exists in a certain position

A very crude approximation must be made to determine the actual line intensity on this early data. Previous calibration indicated that the image orthicon-spectrograph combination has sufficient sensitivity to detect 100 photoelectrons, or approximately 2000 photons at the spectroscope entrance slit. Let us consider this to be "very weak" line, and since the dynamic range of the system is a factor of 200:1, we would expect a "strong" line to correspond to about 4×10^5 photons received in an exposure of about 10 seconds.





Time - EDST - 22-23 September 1963

FIGURE 1 RELATIVE SPECTRAL INTENSITY CHANGES FOR THE SEPTEMBER 1963 AURORA

A slit opening of approximately 1 mm, and 2 cm long was utilized, thus 4×10^5 photons in 10 seconds over a 0.2 square cm aperture over a field of view of roughly 10^{-3} steradians corresponds to a maximum surface brightness B, of

$$B_{max} = \frac{(4 \times 10^5 \text{ photons})}{(10 \text{ seconds})(0.2 \text{ cm}^2)(10^{-3} \text{ steradian})}$$

$$= 200 \times 10^6 \text{ photons} \cdot \text{sec}^{-1} \cdot \text{cm}^{-2} \cdot \text{steradian}^{-1}$$

$$= 2500 \text{ Rayleighs}$$

The above calculation may be optimistic, however it should not be low by more than an order of magnitude.

On the next night of 24 September 1963, sixteen measurable spectra were obtained in the same manner as the first night between 9:30 PM EDST and 11:25 PM, at which time the procedure was changed so that a 35 mm data camera was used to take an exposure every 16 seconds. Much of this latter work was paralleled with image orthicon-motion pictures of the aurora taken at 8 frames per second. Unfortunately, the spectra obtained with the data camera were not of as high a quality as the previous Polaroid prints. Comparison of the spectral movies with the real time movies which were taken simultaneously with the two image orthicon systems shows that:

a) Although the intensity of the 24th September aurora was quite bright, it seemed to be devoid of identifying structures such as brilliant regions or rays, and no dramatic pattern changes were noted except at the very lower boundary. Therefore, no correlation between the spectra and the changing characteristic of the auroral pattern could be detected. This was probably due to the subdued intensity variations over the entire aurora and the wide field of view of the spectrograph -- over 12°.

b) Intensity variations of the spectral pictures (intensity of all lines remaining in a constant ratio) as well as intensity variations in the auroral scene films were observed and could be correlated to a limited degree.

c) Temporal cycles of intensity variations could be detected on the auroral scene films but not on the spectral films. Periodicity of this intensity showed fluctuations ranging from 8 to 40 + seconds.

The grating spectrograph on loan from Dr. C. Gartlein at Cornell University was modified to allow replacement of the plate-holder with an image orthicon camera containing a S-20 tube. The focal length of the collimator was 876 mm, the camera lens was 102 mm, f/1.6, and the grating had 600 lines per inch. A slit opening of less than 1 mm was used.

5.2 Image Orthicon Calibration - North Polar Sequence

Photographic results with the image orthicon on the 16" f/19 Boller & Chivens telescope at the Radio-Optical Observatory provide a point source calibration of the orthicon's sensitivity when the North Polar Sequence of Stars is used as a standard. The resultant field of view displayed on the TV monitor is about 20 minutes of arc = 1200 seconds of arc. As a very optimistic estimate, we can assume that for stars in the range of 15-18th magnitude the image orthicon will have a resolution of 300 lines per field. Thus, one resolution element is 4 x 4 seconds of arc, or 2^4 square seconds of arc (12 db - 3 mag). The dark sky background is approximately 21st mag/sq. sec. of arc, so the equivalent image orthicon background is 18th magnitude per resolution element. Note that for an 18th magnitude star, the sky background will be an equivalent 18th magnitude for the assumed system; actually, the sky

background exhibits granularity which makes the detection slightly more difficult. However, this system should be capable of detecting an object with an apparent magnitude of 18th.

The apparent magnitude of an object depends on the wavelength characteristics of the detector as well as the source. Systematic discrepancies even arise with the same equipment because of equipment variations, and changes in atmospheric attenuation with time. For this reason, a series of stars, the North Polar Sequence, have been calibrated with the greatest possible precision so that their magnitudes are chosen to serve as a standard against which all other magnitude determinations may be compared. These stars lie in the vicinity of the north celestial pole and since 1922 have served to define the universally adopted systems of visual and photographic magnitudes. A note of caution must be inserted here because the magnitudes which are given to the hundredth-place in the original publication have lately been found to possess discrepancies; however, the noticed variations have been less than one magnitude. Photographs 2, 3 and 4 are reproduced plates from the Harvard Annals, Photographic Photometry, Vol. 71, which define the magnitudes of the various stars in the North Polar Sequence.

Figure 5 is an equivalent five second integration of the North Polar Sequence on the 16 inch telescope. The picture was obtained by photographing the monitor of an image orthicon camera system with tri-X film for five successive readout frames, in which the image orthicon operated on an automatic cycle that integrated for one second on the target, and then read out one frame in 1/30 of a second. Even with this relatively short exposure - 5 seconds - an untrained observer can easily identify 16th magnitude stars, numbers 30, 31, and 32, and perhaps even 33, which is 17th magnitude. The bright "star" shaped defect in the center of the photograph is caused by light from the heater of

PHOTOGRAPH 2 NORTH POLAR SEQUENCE
(From Harvard Annals, Volume 71)

PHOTOGRAPH 3 NORTH POLAR SEQUENCE
(From Harvard Annals, Volume 71)

Des.	DM.	Position.	Magn.	Des.	DM.	Position.	Magn.	Des.	DM.	Position.	Magn.
1	+86° 269	. . . . .	4.48	34	. . .	II 74, 80	17.25	7s	. . .	I 74, 76	12.45
2	+85° 383	. . . . .	5.28	35	. . .	II 121,103	17.50	8s	. . .	II 89, 19	14.20
3	+86° 344	. . . . .	5.81	36	. . .	II 113,107	17.75	9s	. . .	II 115, 89	14.47
4	+86° 272	. . . . .	5.99	37	. . .	II 83,140	17.94	10s	. . .	II 172,152	15.02
5	+88° 4	. . . . .	6.49	38	. . .	II 76,118	18.31	11s	. . .	II 58, 80	15.05
6	+89° 13	. . . . .	7.11	39	. . .	II 98,135	18.67	12s	. . .	II 107,195	15.11
7	+88° 64	. . . . .	7.31	40	. . .	II 117,119	19.03	13s	. . .	I 104,103	15.23
8	+88° 9	. . . . .	8.23	41	. . .	II 101,123	19.28	14s	. . .	II 124,192	15.75
9	+88° 13	. . . . .	8.83	42	. . .	II 131, 81	19.68	15s	. . .	II 97, 80	16.42
10	+89° 3	I 132,126	9.02	43	. . .	II 92,125	20.22	16s	. . .	II 90,166	16.72
11	+89° 18	. . . . .	9.55	44	. . .	II 94,124	20.44	17s	. . .	II 52, 66	17.11
12	+89° 25	I 48, 6	9.86	45	. . .	II 91,130	20.74	18s	. . .	II 96, 83	17.91
13	+89° 29	I 42, 46	10.30	46	. . .	II 128,101	21.10	19s	. . .	II 53, 75	18.50
14	+89° 1	I 93,116	10.65					20s	. . .	II 138,133	18.70
15	. . .	I 130, 70	11.08	1r	+87° 51	. . . . .	6.80	21s	. . .	II 63, 75	18.88
16	. . .	I 53,124	11.40	2r	+88° 112	. . . . .	7.87	22s	. . .	II 89,140	18.93
17	. . .	I 31, 89	11.63	3r	+88° 76	. . . . .	8.75	23s	. . .	II 93, 80	19.11
18	. . .	I 42, 98	12.06	4r	+88° 114	. . . . .	9.10	24s	. . .	II 121, 75	19.02
19	. . .	I 67, 86	12.42	5r	+89° 22	. . . . .	9.91	25s	. . .	II 132,127	19.17
20	. . .	I 77, 96	12.73	6r	+89° 9	. . . . .	10.30	26s	. . .	II 145,125	19.43
21	. . .	I 45, 81	12.96	7r	+89° 35	I 55, 67	10.70	27s	. . .	II 111, 76	19.44
22	. . .	I 49, 92	13.19	8r	+89° 31	I 30, 69	11.20	28s	. . .	II 138,135	19.70
23	. . .	I 85, 90	13.34	9r	. . .	I 39, 32	11.70	29s	. . .	II 112,137	20.18
24	. . .	I 59, 89	13.64	10r	. . .	I 76, 39	12.35	30s	. . .	II 92,123	20.32
25	. . .	I 66, 84	13.87	11r	. . .	I 76, 75	12.97	31s	. . .	II 140, 88	20.32
26	. . .	II 43,115	14.33	12r	. . .	I 67, 96	13.48	32s	. . .	II 100,112	20.32
27	. . .	II 114,155	14.69					33s	. . .	II 108,107	20.38
28	. . .	II 141, 18	15.11	1s	+88° 8	. . . . .	2.69	34s	. . .	II 112, 78	20.44
29	. . .	II 146, 36	15.66	2s	+88° 71	. . . . .	6.48	35s	. . .	II 122, 99	20.60
30	. . .	II 133, 18	16.04	3s	+87° 107	. . . . .	6.65	36s	. . .	II 130, 90	20.70
31	. . .	II 68, 81	16.22	4s	+89° 12	I 156, 39	10.12	37s	. . .	II 85,128	20.72
32	. . .	II 146,113	16.62	5s	+89° 37	I 73, 76	10.81	38s	. . .	II 113, 76	21.14
33	. . .	II 25,110	16.96	6s	+89° 26	I 78, 36	11.11				

PHOTOGRAPH 4 MAGNITUDES OF THE NORTH POLAR SEQUENCE
(From Harvard Annals, Volume 71)

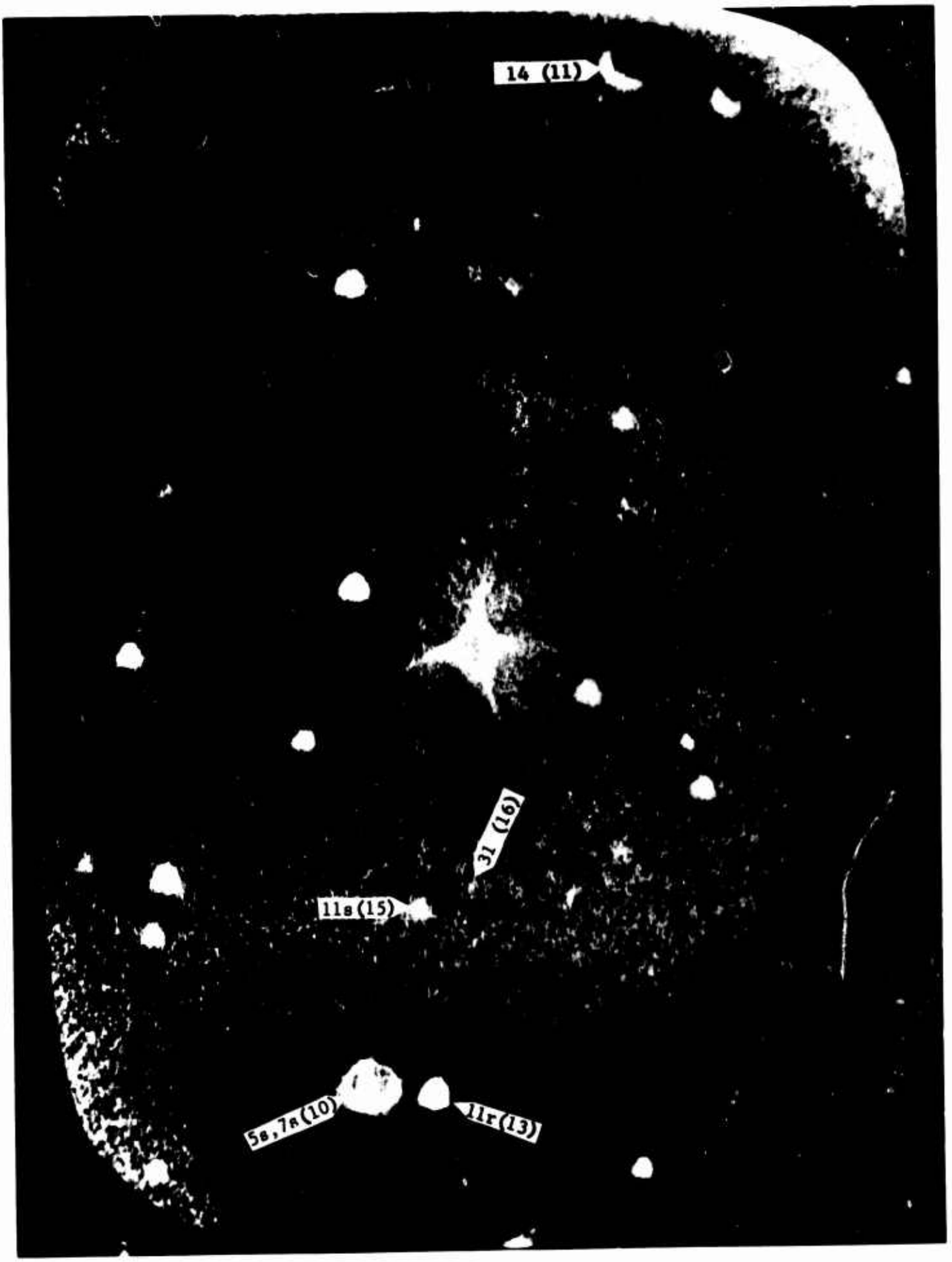


FIGURE 5 IMAGE ORTHICON PHOTO OF THE NORTH POLAR SEQUENCE

Exposure: 1 second on image orthicon target; 5 readout exposures on Tri-X film.
Field of View: 11.25x16 minutes of arc Telescope: 16" f/19
Sky: 2 days past first quarter moon
Center Defect: Integrated light diffracted from I.O. heater.

the image orthicon which has been diffracted by the various internal grid surfaces and integrated sufficiently on the target to resemble an optical signal. This photograph represents the system detectability available on a night with reasonably clear weather. By no means are these results optimum, for on the particular night that this photograph was taken, 10-11 April 1965 at 11:00 PM EST, a slight haze existed under a moon two days past first quarter. Thus, instead of an optimum equivalent sky background of 18th magnitude per resolution element, the background was probably on the order of 16-17th magnitude per resolution element. In fact, if the integration time on the image orthicon was extended to five seconds, severe saturation occurred. Three second integrations on the target were tried with up to 20 readout exposures on film, thereby equivalent to a 60-second exposure. However, under the sky background conditions longer integrations showed no new stars detected over the initial 5-second exposure shown, and only a moderate increase in contrast because of the reduction of grain size in the noise background.

As a further verification to the statements predicting the sensitivity of our image orthicon - 16" telescope system, the weather conditions on the nights of 24-25 September and 2-3 October 1965 fortunately permitted excellent photographs of the North Polar Sequence to be taken with the 11.25 x 16 minute field of view. Figures 6 and 7 illustrate the typical results obtained. Note that on the second night mentioned, the star field was slightly shifted with respect to the boundary of the photographs, as compared to the previous Figures 5 or 6, so that stars numbered 17s (mag 17.1), 18s (mag 17.9), 19s (mag 18.5), 37 (mag 17.9), and 38 (mag 18.3) are not obscured by the center defect caused by the light from the heater of the image orthicon tube in at least one of the photos. Although other stars below 18th magnitude are obscured by the defect, a change in the angle of view would allow detection if the defect did not

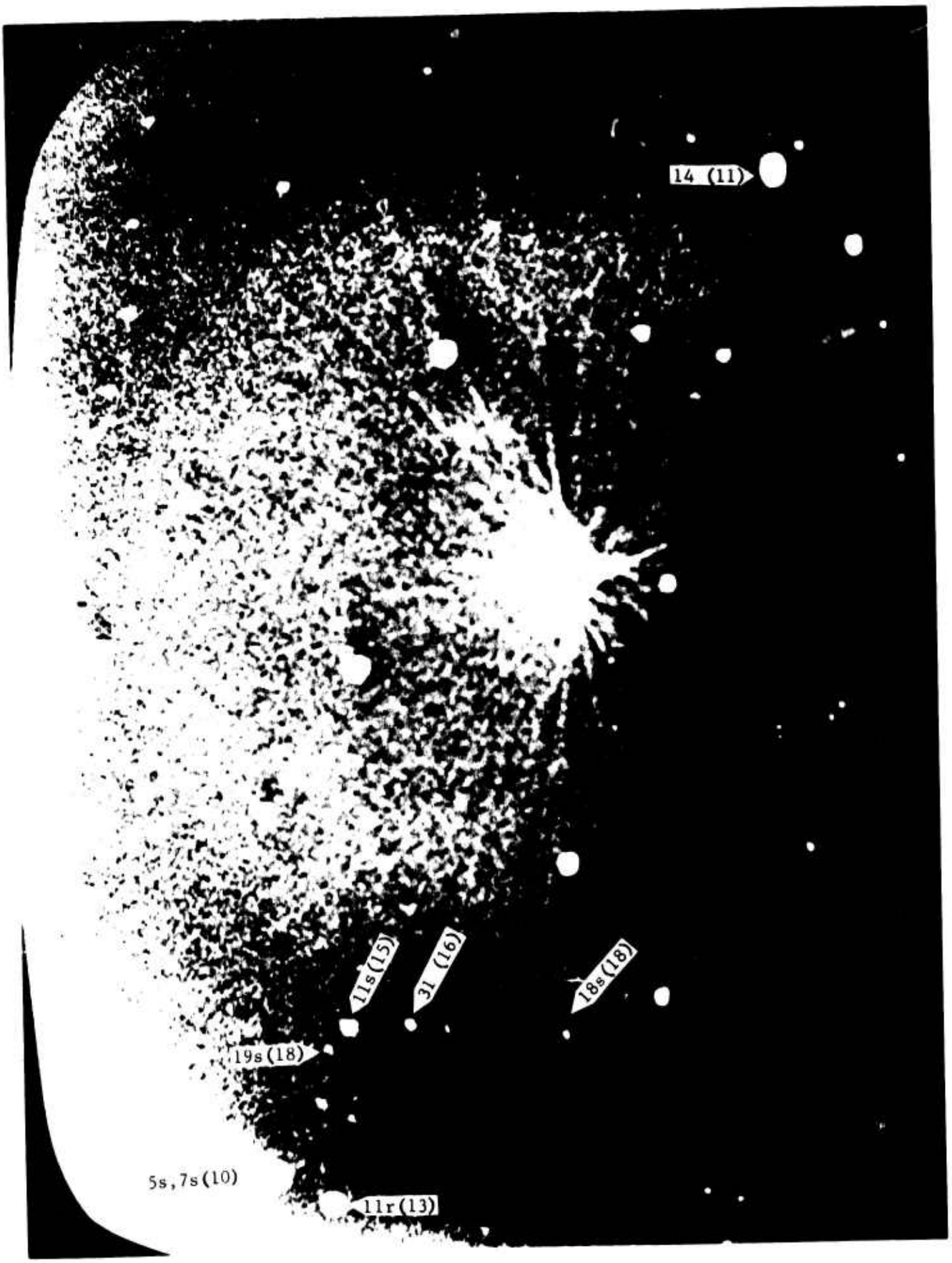


FIGURE 6 NORTH POLAR SEQUENCE

Date: 24-25 September 1965
Exposure on I.O.: 30 seconds
Exposure on Film: 3 I.O. readouts
Field of View: 11.25x16 min of arc

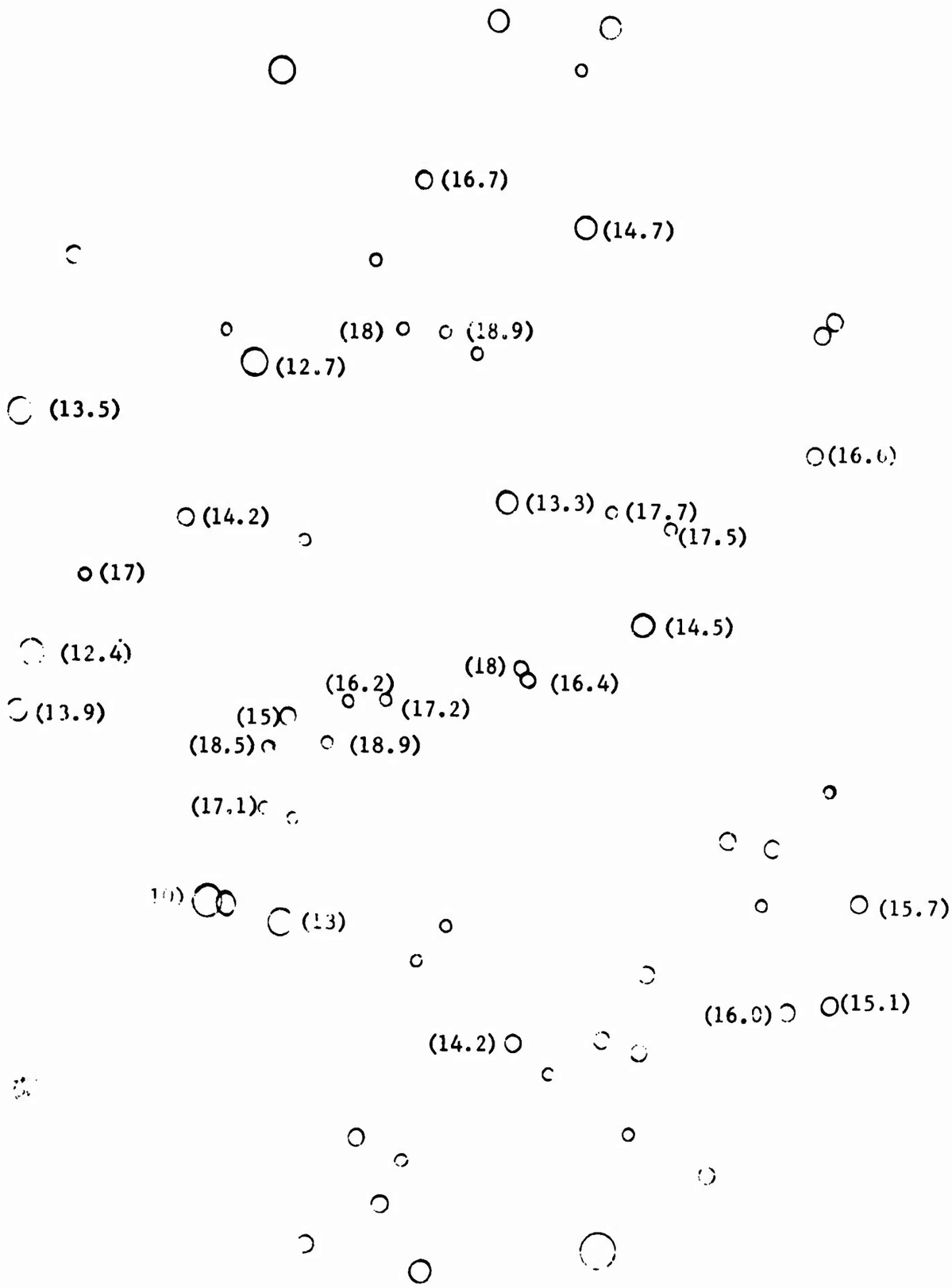


FIGURE 7. STAR MAGNITUDES

Note #1. Stars of 10th to 18.5 mag. are detected - 34 db dynamic range
Note #2. 18.5 mag. corresponds to 20-30 photons/sec at the photocathode
Note #3. Background is 100-200 photons/resolution element
Note #4. The center defect is caused by integrated light from the heater of the image orthicon
Note #5. Star images exceed 3 TV lines in width

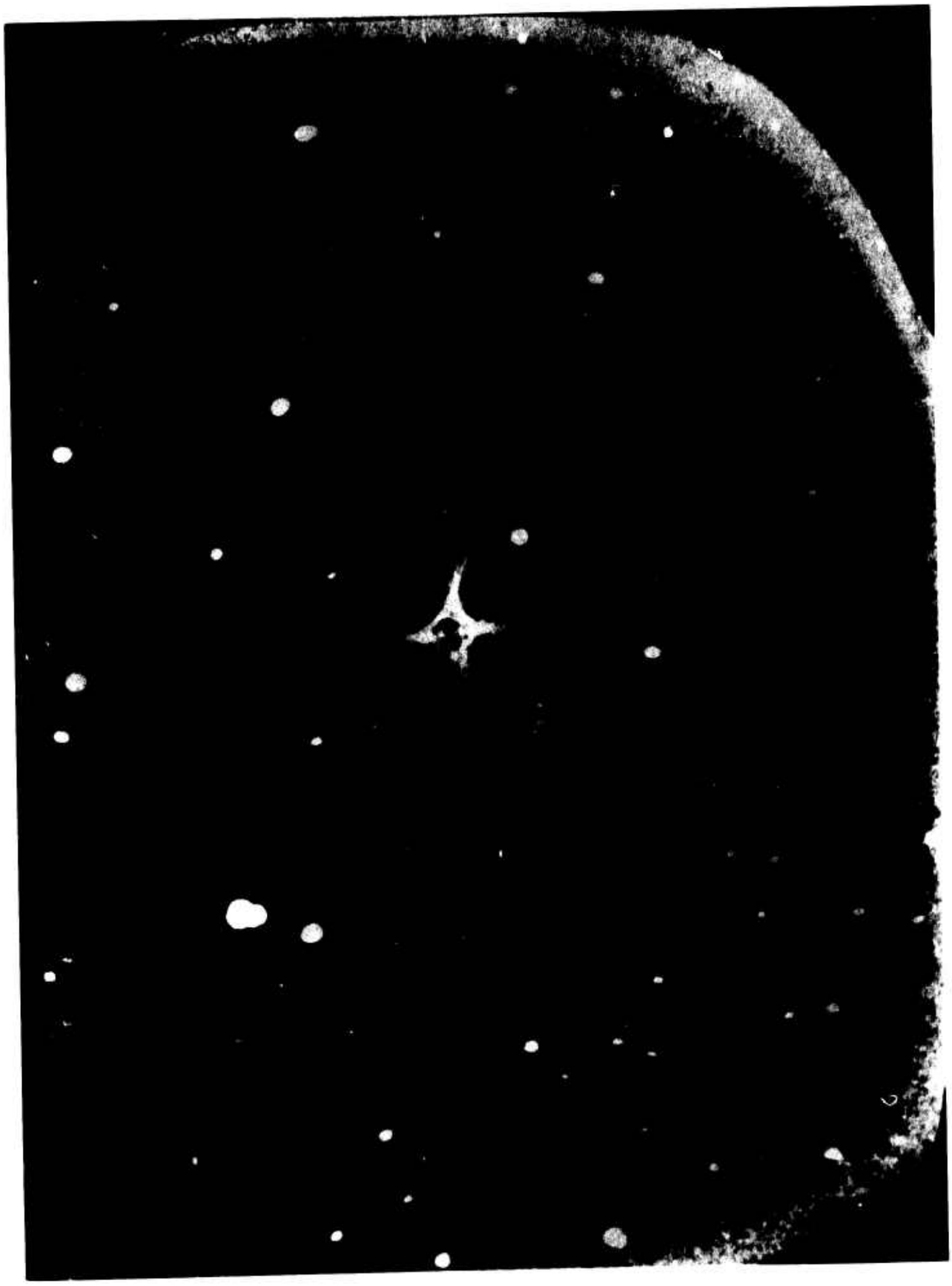


FIGURE 7 NORTH POLAR SEQUENCE

Date: 2-3 October 1965
Exposure on I.O.: 30 seconds
Exposure on Film: 3 I.O. readouts
Field of View: 11.25x16 min of arc

obliterate their signal. The exposures for both photographs of Figure 6 and 7 was a 30 second integration on the image orthicon between each readout, and three readouts were exposed on the tri-X negative. Thus, within 90 seconds 18.5 magnitude stars were detected, and randomly stars 21s and 22s (mag 18.9) were definitely observable in the trial Polaroid exposures. With several 10 second exposures, 18th magnitude stars were definitely detectable; however, the quality of the reproduced photograph in this report was too poor to allow positive identification because of the noise structure, which is made finer grained with three or more exposures on the film.

On the clear night of 30 May 1965 the 16 inch telescope was directed toward the North Polar Sequence for the purpose of locating the star field for further calibration photographs using the wide field of view. The image orthicon camera was positioned at prime focus where the field of view is slightly over $1^{\circ}.5$. The system was operating continuously at 30 frames per second, with one second exposures being taken of the TV monitor on Polaroid film. Because of difficulty in locating the star field, later attributed to the fact that at prime focus the image of the star field is reversed from Cassegrain focus and also that the axis on the monitor was not orthogonal to the equatorial co-ordinates, it was decided to assume that indeed the North Polar Sequence was within our field of view, and commence to take some tri-X negatives of the monitor also using a 1 second exposure on the film. A few exposures were being taken at various f-numbers on the Speed Graphic Camera to be sure that at least one negative had the correct exposure. Just as another exposure was about to be taken, a bright object (later determined to be a satellite) was noticed to have entered the edge of the monitor and the shutter was quickly opened. The resultant photograph is shown in Figure 8 and an expanded view in Figure 9. Notice that the camera shutter closed slightly before the

FIGURE 8 IMAGE ORTHICON PHOTO OF THE NORTH POLAR SEQUENCE

Exposure: 1 second on Tri-X film, with I.O. operating at 30 frames/second.
Field of View: 1.5^{o} Telescope: 16" f/4 Sky: Clear, dark
Bright line: Satellite (5-6 magnitude) traveling towards the lower right portion of the photo.

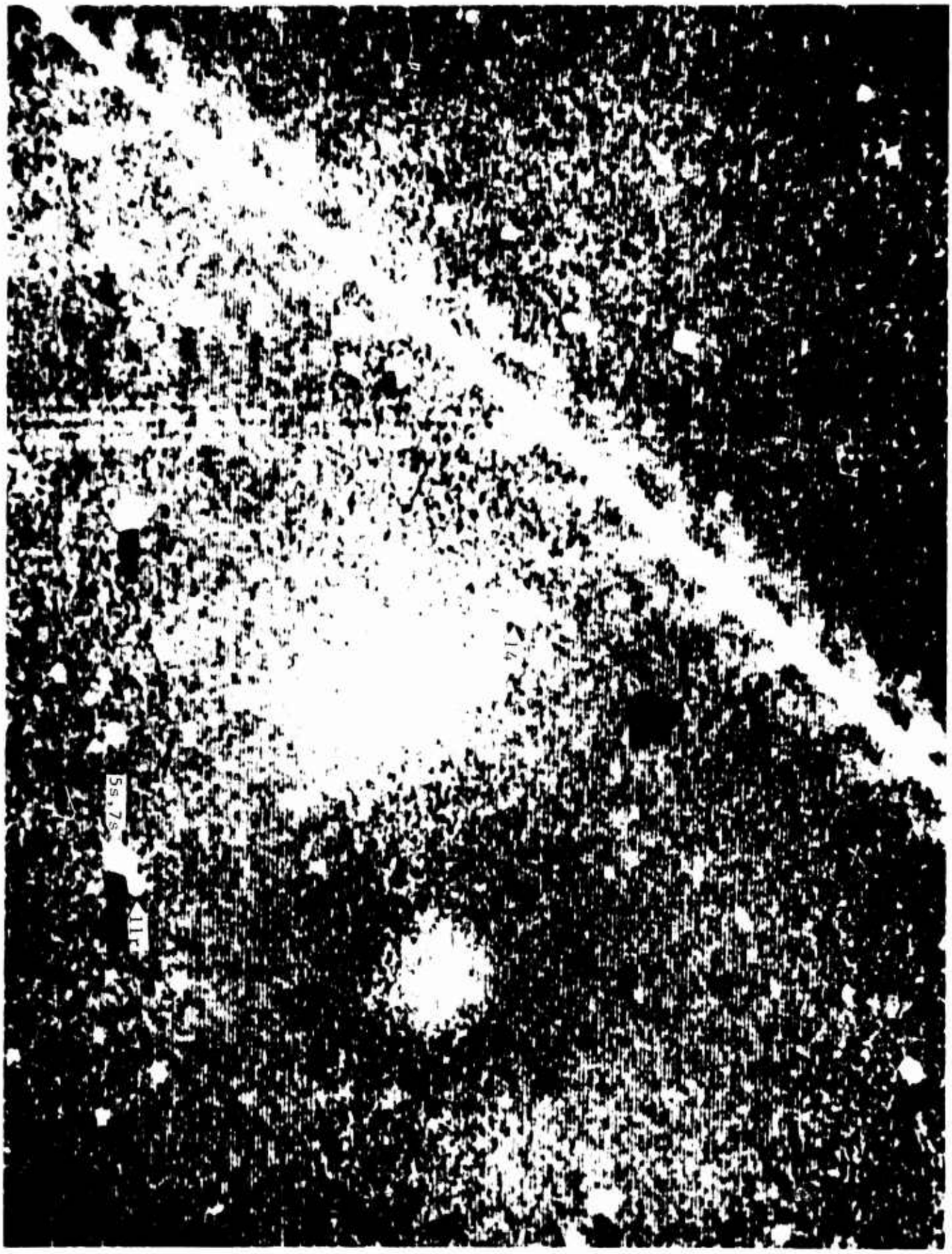


FIGURE 9 EXPANDED VIEW OF FIGURE 8

satellite left the field of view. Had we known the exact time the shutter closed, it would have been possible to tell the position of this satellite well within 1/30 of a second anywhere along its path. The estimated satellite magnitude is 5-6.

Because the satellite image was so intense, severe saturation effects on the image orthicon produced little rings between each of the 1/30 second read-outs. This effect is caused because the intense beam of photoelectrons caused sufficient space charge to deflect the secondary electrons back on the target. Note that the diffraction pattern does not exhibit itself since the wider field of view has a larger background noise to hide the effect. Blemishes on the target show as black spots; the black spots trailing very bright stars are caused by saturation in the video amplifiers. The vertical lines are caused by a transient in the return horizontal sweep which is picked-up by the video amplifier. Also note that star 11s (magnitude 15.05) of the North Polar Sequence is quite detectable with this 1 second exposure on a $1^{\circ}.5$ field of view. In fact, a trained observer can certainly identify star #31 in the original print at magnitude 16.22. This corresponds to about 250 photons from the star and about an equal intensity per resolution element from the background. By slowly trailing the star images, it was found that the detection for a point and line image had equal sensitivity.

No direct demonstration of the ability to detect fainter objects has been made at the time of this writing. However, the photographs of the North Polar Sequence made with the image orthicon at the prime focus of the telescope, resulted in a field of view such that the resolution was 16 seconds of arc instead of four. As a result, the sky brightness per resolution element was 16 times greater than with the camera at the Cassegrain focus as is normally used. The photograph with the wide field, made on a very dark, clear night by

Schenectady standards, easily revealed a star of 15th magnitude. Extrapolating from this observation, it is estimated that 18th magnitude stars could have been detected within 1 second on that night if the image orthicon camera had been at the secondary focus. The above data compares quite favorably to that of Fitz-Hugh Marshall[9] in detecting faint point sources with an image orthicon.

These photographs illustrate some unusual characteristics of image orthicons when applied to the detection of point sources. Note that regardless of the star magnitude, all stars are at least 2 T.V. lines wide, if not 4-10 lines wide. This property is not due entirely to a charge spread during the long integration times, for during continuous 30 frame per second operation, the signals from well focused stars of equivalent brightness on the monitor display a similarly large diameter. This effect is probably due to enormous potential gradients at the narrow image of charge which attract the scanning beam during readout, since the 16-inch telescope Airy disk is about 0.4 seconds of arc, while the T.V. resolution is 12 seconds at prime focus and 4 seconds of arc at Cassegrain focus.

Also stars of 18.5 and 10th magnitude may be photographed within the same field of view without blooming. This brightness difference is 34 db or over 2000:1.

With a slight degree of engineering, the most objectional comment on the photograph may be corrected; that is, the center defect caused by the diffracted light from the heater. Since no heater is required during integration, some means could be devised to turn it off during the exposure period on the image orthicon.

5.3 Night Air Glow

Night air glow spectra have been recorded with integration periods on the image orthicon tube varying from 0.1 seconds to minutes. One to 10 second exposures are adequate for most purposes and compare quite favorably with exposures on film of 1 to 2 hours. The final report of December 1963[1] discusses the very general observations in the recorded data and may be briefly summarized.

i) Mercury lines from scattered city lights are always detected regardless of the angle of view. The Observatory is situated about 8 miles away from the nearest two towns; the horizon is dark to the human eye in the other directions.

ii) At night the green line - 5577Å - is always detected except during full moon with 100% overcast.

iii) If the red line - OI 6300Å - 6364Å - is detected at all, relatively fast fluctuations in the intensity are usually observed. Under this condition the red line could be detected on the average of one plate out of 3 or 4 when one second exposures are used. With 10 second exposures the red line is always recorded. However these noted fluctuations could have been due to time variations in the atmospheric attenuation because of clouds and haze or a weak aurora may be causing the pulsations. In any case even during the best observation periods, considerable haze existed up to a 30° elevation. With thick haze and clouds the red line could never be detected.

iv) During some part of the study period, the following night air glows were detected:

Hg	4047
	4078
	4358
	5461
	5770
	5790
	6907
	7082
NaD (Twilight)	5890
	5896
N_2^+	3914
	4278
	4652
	4709
	5228 (Guess)
OI	5577
	6300
	6364
NI	5199 (Guess)
H_α	6563

Since spectral photographs obtained by others have shown which night air glow lines exist, new information must be generated in the area of correlation in the rapid time changing characteristics or emission delays between the various lines, or in the night-to-night changes, or with some other observable physical characteristic. Unfortunately the weather has prevented any regular observing program at Schenectady, New York. Even on the relatively clear nights, scattered clouds and haze has even made observations difficult. In addition, the auroral minimum coupled with the weather blackouts has prevented the detection of any visual aurora to give the equipment a fair test.

Typical night air glow and auroral photos taken on different nights with the two spectrographs are shown in Figure 10, with captions that are quite self-explanatory. During all of these tests the photometer had insufficient sensitivity to provide an absolute calibration on night air glow.

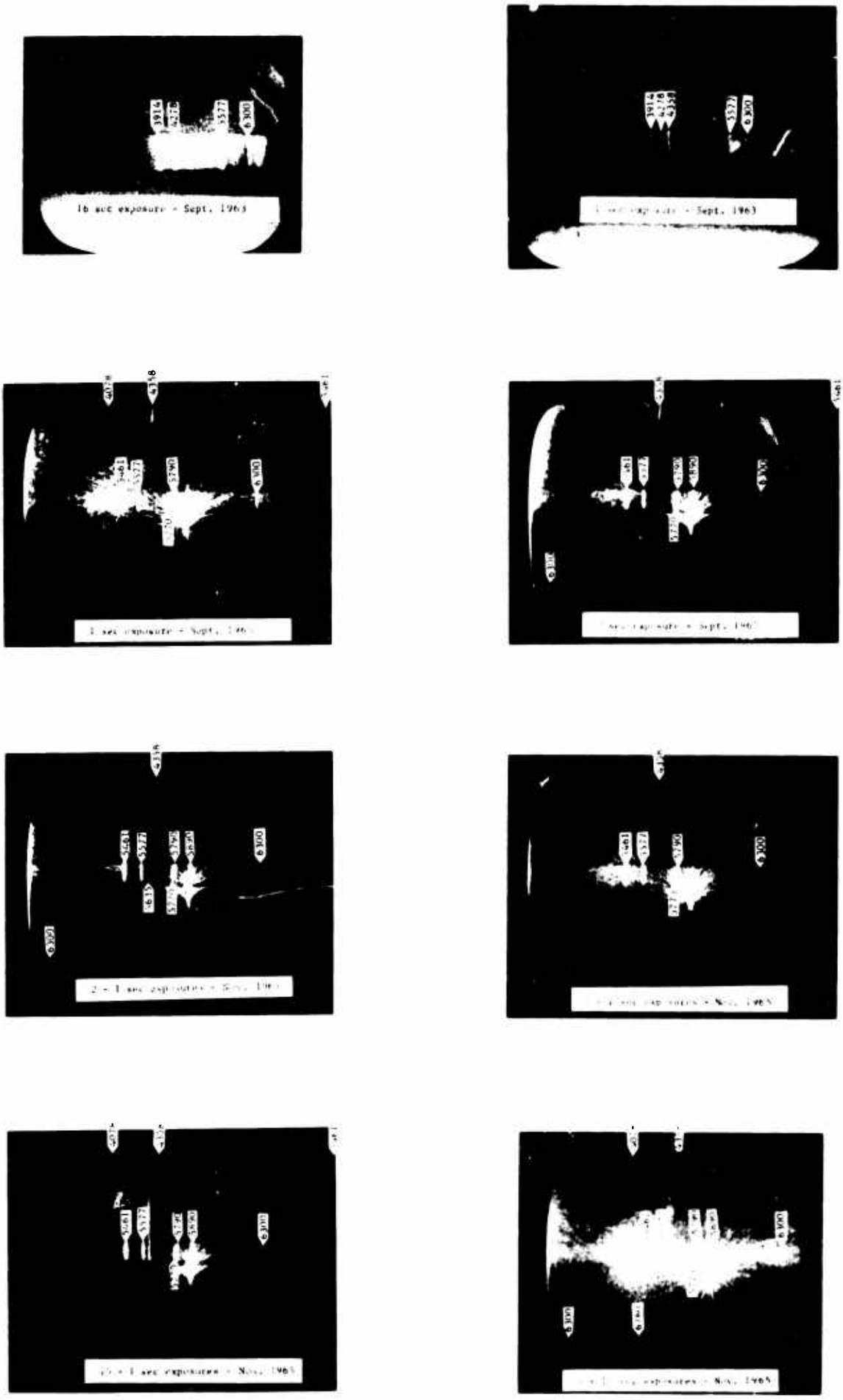


FIGURE 10. Typical Spectra Photographed Using the Image Orthicon Spectrograph (Defect caused by integrated light from the heater of the image orthicon.)

5.4 Image Orthicon Characteristics

By use of a precision photometer a few of the intense auroral lines may be accurately measured so that all the spectral lines detected with the image orthicon-spectrograph system may be given an absolute intensity calibration as is pointed out in the Appendix.

The control voltages on the image orthicon allow a wide latitude or range of average signal intensity levels to be read out. This latitude range is perhaps greater than 10,000:1. At any one particular setting of the controls, when optimized for the best performance on the given latitude level, the true dynamic range is about 20-60:1 in perhaps 10 gray scales, depending on the effect of the multiplicity of interactions between the various grid surfaces. However, with point or line sources a pseudo-dynamic range of 200:1 in 20 resolvable steps can be achieved by using both signal amplitude and width as a criterion for determining signal intensity. Although a dynamic range of 200:1 is marginally useful, a basic question may arise as to how this range can be extended. There appear to be two fundamentally different techniques that can be applied. The first is the use of beam feedback controlling the beam current on a point-to-point basis so that the beam current will be sufficient to discharge the target under any conditions. The primary difficulties here are in obtaining feedback stability with the very weak beam currents that are necessary to just erase the accumulated target charge for the optimum detection of extremely low light level signals. Additionally, the finite delay that inherently exists in the beam feedback loop may preclude correction for point source images. The signal width is not a beam current problem, but is rather inherent in the electric field since the acceleration of the beam by the target charge distribution leads to secondary electrons being ejected by the target before the scanning beam reaches the narrow charge image. The

result displayed on the monitor is widened signals for more intense images. Although this technique is promising with extended objects at higher light levels, perhaps no advantage may exist at very low light levels.

The second technique is sometimes termed target slicing and is discussed in the 7 December 1963 Report[1]. It depends on the fact that the overload characteristics at low light levels are caused by beam attraction, and are not inherent in the target. Using this method, the target mesh is monotonically biased in increasing steps during successive frame readouts so as to reduce the high charges in the earlier readouts; faint signals are thus read out after the large charge distributions have been partially discharged. Initial breadboard tests of this mode indicate a dynamic range improvement factor of perhaps 10. Improved readout of neighboring bright and dim lines is also realized.

Absolute intensity calibration is a very difficult problem because the image orthicon readout has a number of operational uncalibrated effects. These are caused not only by slight potential changes between the various grids, but also by regional changes in the charge distribution on the target surface, due to variations in the average signal level or to a redistribution of the relative signal strength. With the image orthicon spectrograph, the best method of intensity calibration seems to be correlation through the measurement of the few intense spectral lines by the use of narrow band optical filters and a photomultiplier. Assuming that this measurement may be a good standard, adjacent spectral lines of weaker intensity can be given a relative calibration. Wavelength calibration measurements on the equipment over the spectrum of 3800Å to 8200Å show a 5-30Å resolution depending upon the signal characteristics. A 5Å resolution is possible if a known line exists within a 20Å deviation, and all lines in the immediate region do not possess widened images due to overexposed saturation effects. If no near calibrated lines exist, a 10Å resolution

is easily possible, except [illegible] the case of highly overexposed lines which may widen to as much as 50Å.

The following discharge lamps assist in the spectral calibration of the three-slit spectrograph-image orthicon system.

i) Hydrogen - H_4

ii) Helium - He

iii) Argon - Ar

iv) Neon - Ne

v) Sodium - Na

vi) Mercury - Hg

Stability of the equipment allows a wavelength determination to better than 10Å over the spectrum range of 3800Å to 8300Å. The intensity of the spectral lines may be broken up into at least 20 resolvable steps covering a dynamic range of 200:1 except for wavelengths shorter than 4000Å where the attenuation reaches about an order of magnitude at 3900Å, and perhaps two to three magnitudes at 3800Å.

Although the wavelength calibration procedure is relatively simple, it is accomplished more easily if the image orthicon has a very linear readout and assists in data analysis. The following method was judged most effective in providing a linear alignment on the image orthicon readout.

If a linear monitor is available, the image orthicon may be easily aligned with respect to linearity by using two square wave generators and a cross-hatched pattern of white and black bars. When a cross-hatched chart of black and white rectangles is optically imaged on the image orthicon tube and the resultant signal is displayed on the monitor along with output of two stable square wave generators producing the same spatial frequencies, a difference signal will be very evident when synchronization is achieved. This difference signal will

null to a constant distance when linearity is optimum. Variation in the difference will indicate the non-linearity between the monitor and the image orthicon sweep circuits.

The monitor may be aligned by only impressing the signals from the square wave generators on the monitor so that the linearity of the bar pattern on the monitor only depends upon the linearity of the monitor. Thus with a straight edge and scale, the monitor may be made linear by the adjustment of the appropriate electronic sweep circuit parameters.

6.0 PERSONNEL

The following named personnel actively participated in support of this auroral study at the General Electric Radio-Optical Observatory during the noted intervals within the contract period.

J. E. Anderson

Project Responsibility - November 1964 to December 1965
Project Assistant - September 1963 to October 1964

Engineer - Electronics
Electronics Physics Laboratory
Research & Development Center

BSEE - University of Wisconsin - 1960
MSEE - Polytechnic Inst. of Brooklyn - 1965

Mr. Anderson is responsible for work in the electro-optics area at the Research & Development Center. Currently, he is performing development work with room-temperature operating diode lasers at high repetition pulse rates, as well as applying the use of coherent light radiation to the precise measurements field. Also the design and operation of low light level image orthicon chains, photometers, and other optical detectors used for observational astronomy, space vehicle detection and tracking have been his direct concern at the General Electric Radio-Optical Observatory. In addition, Mr. Anderson was a member of a team that was notably successful in receiving video signals transmitted by Rangers 8 and 9, from which detailed lunar photographs were produced.

Since 1963 he has performed studies and experimental investigations in laser modulation and detection, atmospheric propagation, optical detectors, and image orthicon application to areas such as auroral spectroscopy and ground surveillance.

As a BSEE graduate of the University of Wisconsin, Mr. Anderson joined General Electric on the Company's Engineering & Science Program, and spent his first year-and-a-half in research and development work on high-frequency (100 MHz to 1 Ghz) tunnel diode circuits, voltage ratio devices, saturating moving core transformers, strain gage indicators, and air flow testing on T64 jet engines. In 1961 he permanently joined the Research & Development Center for investigations of mutual coupling between antenna arrays, microwave circuits, and parametric amplifiers, the work of which has evolved into the electro-optical field. He completed the General Electric sponsored Advanced Engineering Course and recently received a Master's degree in engineering from the Polytechnic Institute of Brooklyn.

J. F. Spalding (Presently with Perkin-Elmer, Norwalk, Conn.)

Project Responsibility - November 1962 to November 1964

Engineer - Optical Instrumentation
Electrical & Information Engineering Laboratory
Advanced Technology Laboratories

BS in Physics - Michigan State University - 1951

Mr. Spalding was born in Toledo, Ohio. From 1944 to 1946 he served in the European Theater in the Infantry and was discharged a Sergeant. He attended the University of Chicago from 1946 to 1949 majoring in Philosophy and Michigan State University from which he received his degree in physics.

In 1951 Mr. Spalding was employed by Lick Observatory, working first as an optician at Mt. Wilson and Palomar Observatories and then as an astronomer's assistant at Mt. Hamilton. He was Junior Optician on the 120-inch telescope project. From 1953 to 1955 he attended graduate school at the University of California, majoring in astrophysics.

In September, 1955, Mr. Spalding joined the General Electric Company with the Light Military Electronics Department in Utica, New York as a Product Design Engineer. At Utica he worked on both mechanical and electrical problems on the ARR 39 system; mathematical analysis of velocity damped inertial guidance computers for missiles. In 1958 he became a digital design engineer on the Polaris fire control system. In 1959 Mr. Spalding joined the General Engineering Laboratory (now Research & Development Center) as an engineer in optical instrumentation for observing re-entry of ICBM nose cones, and in 1964 he joined Perkin-Elmer, Norwalk, Conn.

Mr. Spalding is a member of the American Physical Society, American Astronomical Society, and the Institute of Radio Engineers. He is a member of Sigma Pi Physics Honorary Society.

Dr. P. R. Lichtenstein

Consultant - January 1965 - December 1965
Research Associate at Rensselaer Polytechnic Institute

In addition, the many helpful discussions, advice, memos and newsletters from Drs. C. W. Gartlein and G. Sprague of the IGY World Data Center A, Cornell University, Ithaca, New York are gratefully acknowledged and appreciated.

REFERENCES

1. J. Anderson & J. Spalding, "Application of Electro-Optics to Auroral Studies," AFCRL 64-209 (December 1963).

2. J. Spalding & C. L. Hemenway, "Meteor Observations with an Image Orthicon," Astronomical Journal 66, no. 2, p. 54 (March 1961).

3. G. T. Hicks & T. N. Davis, "Television Cinemaphotography of Auroras and Preliminary Measurements of Auroral Velocities," Jr. of Geophysical Research 69, 1931 (1964).

4. G. T. Hicks and T. N. Davis, "Cinematography of Spatial and Temporal Variations in Auroral Forms with an Image Orthicon TV System," Applied Optics, 4, no. 2, pp. 187-188 (February 1965).

5. J. W. Chamberlain, "Physics of the Aurora and Air Glow," Academic Press 1961.

6. C. Störmer, "The Polar Aurora," Oxford University Press, 1955.

7. International Auroral Atlas, Edinburgh University Press, 1963.

8. E. B. Armstrong & A. Dalgarno, "The Airglow and the Aurorae," Pergamon Press, 1956.

9. Fitz-Hugh Marshall, "Image Orthicon Threshold Detection of Stars and Satellites," Infrared Physics, 4, no. 3 (October 1964).

APPENDIX

DRAFT OF AN ARTICLE SUBMITTED FOR PUBLICATION
TO THE REVIEW OF SCIENTIFIC INSTRUMENTS

Image Orthicon Slit Spectrograph

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Research & Development Center, General Electric Company
Schenectady, New York

One of the instruments developed at General Electric's Research & Development Center is a sensitive image orthicon slit spectrograph for the investigation of aurora and night air glow, particularly with respect to their time-changing characteristics. The equipment design as described leads to the following equipment specifications: sensitivity - 20 photoelectrons produce a detectable signal; dynamic range - 200:1; resolution - 5-30Å; spectrum coverage - 3800Å to 8200Å; typical exposure required on a just-visible aurora - 1 second, on night air glow - 10 seconds.

INTRODUCTION

Investigation of night air glow and auroral spectroscopy began in 1921 when Vegard, with his able assistants, obtained numerous photographs, including those of the first infrared spectra. Since that time, observers have attempted to obtain high resolution photographs of the time-changing characteristics of auroral and night air glow line intensities. However, with a slit spectrograph the amount of night air glow radiation reaching the film usually requires, even with a fast f/0.6 optical system, integrations on the order of hours to provide an exposure level sufficient for adequate recording. Needless to say, with either film or an integrating photometer as a detector, the relatively long exposures required destroyed much of the rapid time changing information

on the relative intensity changes between the various spectral lines. But with the advent of very sensitive image orthicon tubes such as the General Electric GL-7967, which require only 20 photoelectrons to produce a detectable point or line source signal under high contrast conditions, a detector has become available to reduce the exposure time below that previously required. In return for spectral information on the rapid time changing characteristics of dim auroras, a dynamic range limitation of 200:1 in perhaps 20 resolvable levels exists between the relative intensities of the respective spectral lines with the image orthicon detection system.

From our initial experimental investigations of the techniques required in TV auroral cinemaphotography as reported to the American Astronomical Society's 107th meeting in December, 1960[1], others such as Hicks and Davis[2,3] have reported further progress in recording auroral forms. Meanwhile our interest has been directed to the measurement of the spectral distribution of aurora and night air glow using the image orthicon. With the loan of an auroral spectrograph from Dr. C. W. Gartlein of Cornell University for the purpose of investigating auroral spectroscopy, those parameters affecting the mating of an image orthicon to a spectrograph were determined. An image orthicon spectrograph of superior design resulted and is described below.

DESCRIPTION OF THE INSTRUMENT

The image orthicon slit spectrograph consists of three important parts. First, the slit spectrograph, which must be made compatible with the 3:4 aspect ratio of the image orthicon scanned surface for a high spectral resolution and a wide spectrum coverage; second a well-engineered sensitive image orthicon system that allows target integrations varying from milliseconds to minutes, with a single frame readout mode; and third, instrumentation to provide a means of accurate calibration.

The conventional grating slit spectrograph design consists of a slit, collimating lens, grating, and focusing lens, as shown in the schematic of Figure 1. The resultant spectrum has an image height which is roughly the product of the slit height times the ratio of the focal lengths of the focusing and the collimating lens. The spectrum length depends upon the spectrograph dispersion, as determined by the grating and optic parameters. In auroral use, it is very much broader than the image slit height. Thus, the problem of using the image orthicon as a detector is to project the image spectrum with an aspect ratio of perhaps 20:1 onto an image orthicon detector with a 3:4 aspect ratio, while maintaining a maximum in resolution. The solution was to separate the spectrum into three sections covering the overlapping ranges of 3800Å to 5300Å, 4800Å to 6600Å, and 6300Å to 8200Å, and then optically stack the image of these three sections within a rectangular image plane, having a 3:4 aspect ratio and a diagonal dimension equal to the 4 cm photocathode surface. The design goal was to obtain 10Å resolution.

A typical photograph of the wavelength calibration spectrum as seen by the image orthicon with this spectrograph using the low dispersion grating, is shown in Figure 2. The stacking of the spectral images is accomplished by using three slits with calibrated widths, displaced with respect to each other in both the horizontal and vertical plane as shown in the equipment of Figure 3. The two outer slits which determine the blue and red portions of the imaged spectrum have prisms to correct their angle of view so that in the image plane all three slits are inspecting the identical region of the sky and have the same field of view. Behind the slits, the spectrograph design uses a 92 cm f/9 collimator lens and a 15.3 cm f/1.5 camera lens where one of two gratings may be used. The high dispersion grating has a ruled area of 76 x 65 mm at 2160 grooves/mm, and the low dispersion grating is 100 x 100 mm ruled at 600 grooves/mm. Figure 4 is a curve of the measured image width for various slit openings.

The image orthicon system is a special design of the Research & Development Center specifically directed towards the investigation of astronomical applications. The image orthicon tube, General Electric model GL-7967, has an S-20 extended red response photocathode and a magnesium oxide target for maximum sensitivity. Independent voltages and controls regulate the various grid potentials to at least 0.1%; thus providing a minimum of electronic interference as well as a variety of operational modes, which include provisions for target integration, multiple frame readout, microsecond exposures, and clock synchronization to within microseconds. The resultant stability permits a night-to-night duplication of results for identical illumination conditions. The single frame readout is a standard 1/30 second, 525 line non-interlaced scan. Since most applications use only a single frame readout after an integration period, particular emphasis was placed on the low noise preamplifier and amplifier circuits so that transients would not degrade the picture quality. The measurements on the amplifier indicate a 4 db noise figure and a bandwidth of 15 Hz to 9.8 MHz at the 3 db points, when corrected to compensate for the estimated 15 pf of shunt anode capacitance across the 50 kilo-ohm preamp input resistance. All video signals are transmitted through 75 ohm coaxial cables having matched terminations on each end. Two 20 cm monitors with a blue phosphor P-11 response are used to obtain photographs with a 35 mm synchronized data camera or a 4" x 5" Speed Graphic camera.

A photometer with an EMI9558B photomultiplier viewing the same area of the sky as the spectrograph is used to monitor one of the following brightest auroral emission lines for the purpose of an absolute intensity calibration:

N_2^+ - 3914Å; N_2^+ - 4709Å; IO - 5577Å; OI - 6300Å; H_α = 6563Å.

With this information, the other spectral lines observed on the image orthicon may be given a relative intensity calibration.

EXPERIMENTAL RESULTS

Tests with the developed image orthicon spectrograph demonstrate a sensitivity sufficient to detect a line strength equivalent to less than 20 photoelectrons, when a weak signal with a high signal-to-background noise ratio exists. This sensitivity with a line source was found to be equivalent to that obtained with a point source. Image orthicon calibrations on the North Polar Sequence of stars with a 40 cm aperture, f/19 telescope have demonstrated the detection of 19th magnitude stars with a 30-second exposure and 17th magnitude stars with a one-second exposure. With the 40 cm aperture, 17th and 19th magnitude correspond to roughly 150 photons/second and 24 photons/second respectively at the detector when the optical efficiency of 70% is assumed.

When the efficiency of the spectrograph is considered, similar sensitivity measurements result on night air glow with the image orthicon spectrograph. Conventionally, the aurora-airglow units of surface brightness are measured in Rayleighs, where $4\pi \times 10^6$ photons $sec^{-1} \cdot cm^{-2} \cdot ster^{-1}$ is taken as 1 Rayleigh[4]. Since the image orthicon spectrograph parameters are:

20 photoelectrons for detection

10% photocathode efficiency

20% spectrograph efficiency

1000 photons for detection at the slit

1 second exposure

1 mm x 10 mm slit size

6° field of view $\sim 10^{-2}$ steradians

then the minimum surface brightness $B_{\wedge min}$ required for detection of a line is

$$B_{\wedge min} = \frac{10^3 \text{ photons}}{(1 \text{ sec})(0.10 \text{ cm}^2)(10^{-2} \text{ ster})}$$

$$= 10^6 \text{ photons} \cdot \text{sec}^{-1} \cdot \text{ster}^{-1}$$

$$= 4\pi \text{ Rayleighs}$$

For longer integration periods the sensitivity varies roughly as the square root of time until saturation is reached in 10-50 seconds, depending on the background.

Although extended periods of inclement weather have limited the observation frequency, up to 10 night air glow and mercury lines have been successfully recorded with 0.1 second to 60 second integrations on the image orthicon target. Figure 5 is a reproduction of a typical photograph where a 10 second image orthicon integration and one frame readout was exposed on the film viewing the monitor. The center defect has been caused by diffracted light from the heater of the image orthicon, which has also integrated on the target. Note that the OI 6300Å red line has been detected within 10 seconds. Normally, this has been the case. If one second integrations are used, the fluctuations are such that on the average the red line is definitely detectable on 3 out of 10 photos. The OI 5577Å green line is always detected with 1 second exposures and many times within 0.1 second. On very clear nights, several N_2^+ lines are detected. The mercury lines caused by scattered city lights are always detected over the entire sky, even in the darkest region away from any city.

Even though the quality of this photo has been degraded by enhancing the contrast to facilitate reproduction, a dynamic range limitation does exist. The control voltages on the image orthicon allow a wide latitude, or range of average signal intensity levels, of perhaps greater than 10,000:1, to be read out. At any one particular setting of the controls, when optimized for the best performance on the given latitude level, the true dynamic range is about 20-60:1 in perhaps 10 gray scales, depending on the effect of the multiplicity of interactions between the various grid surfaces. However, with point or line sources a pseudo-dynamic range of 200:1 in 20 resolvable steps can be achieved by using both signal amplitude and width as a criterion for determining

signal intensity. Although a dynamic range of 200:1 is marginally useful, two fundamentally different techniques are being applied to extend the range by a few orders of magnitude. The first is the use of beam feedback controlling the beam current on a point-to-point basis so that the beam current will be sufficient to discharge the target under any conditions. The second technique depends on the fact that the overload characteristics at low light levels are caused by beam attraction, and are not inherent in the target. Using this method, the target mesh is monotonically biased in increasing steps during succe[illegible]rame readouts so as to reduce the high charges in the earlier readouts; faint signals are thus read out after the large charge distributions have been partially discharged.

The best method of absolute intensity calibration seems to be correlation through the measurem[illegible] the few intense spectral lines by the use of narrow band optical filters and a photomultiplier. Assuming that this measurement may be a good standard, adjacent spectral lines of weaker intensity can be given an absolute calibration. Wavelength calibration measurements on the equipment over the spectrum of 3800Å to 8200Å show a 50-30Å resolution depending upon the signal characteristics. A 5Å resolution is possible if a known line exists within a 20Å deviation, and all lines in the immediate region do not possess widened images due to overexposed saturation effects. If no near calibrated lines exist, a 10Å resolution is easily possible, except for the case of highly overexposed lines which may widen to as much as 50Å.

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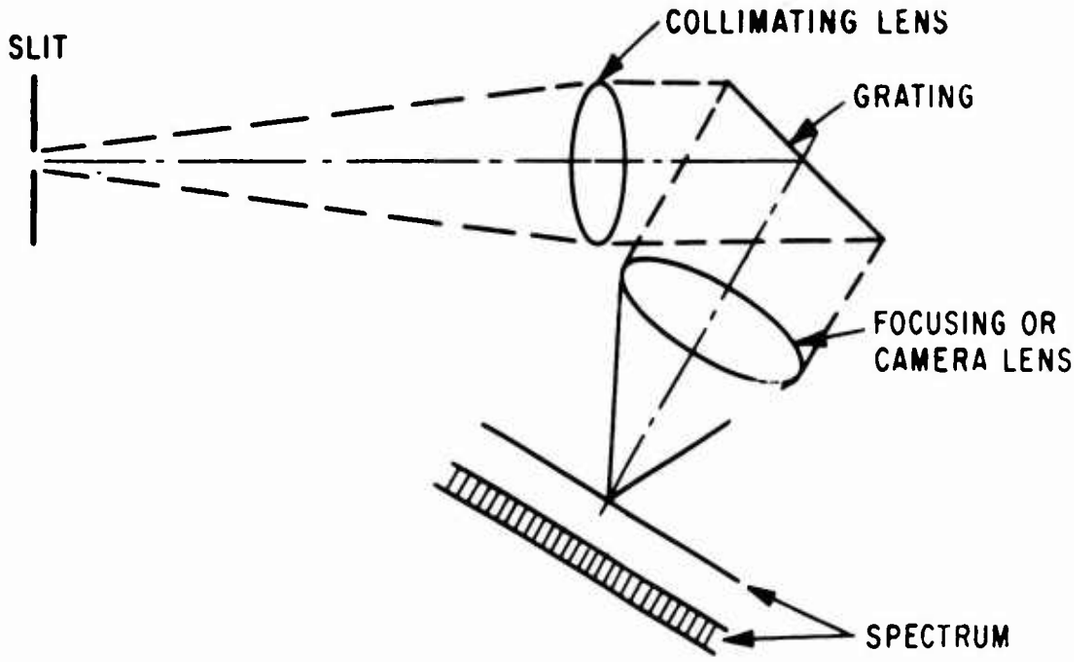

Figure 1. Conventional Grating Slit Spectrograph Design

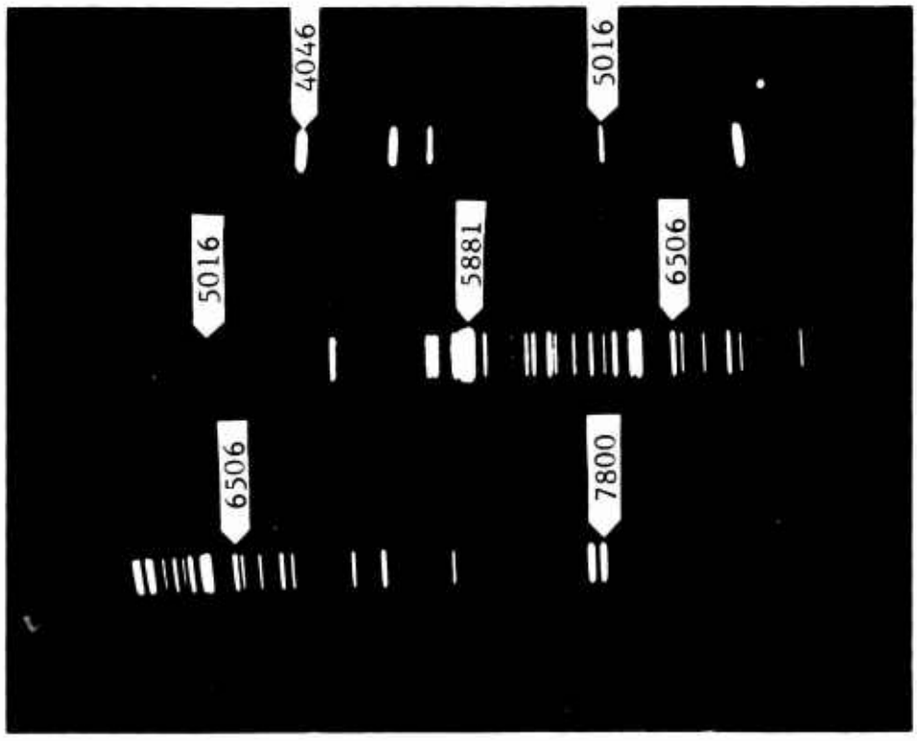

FIGURE 2. PHOTO OF OBSERVED CALIBRATION SPECTRUM ON THE IMAGE ORTHICON

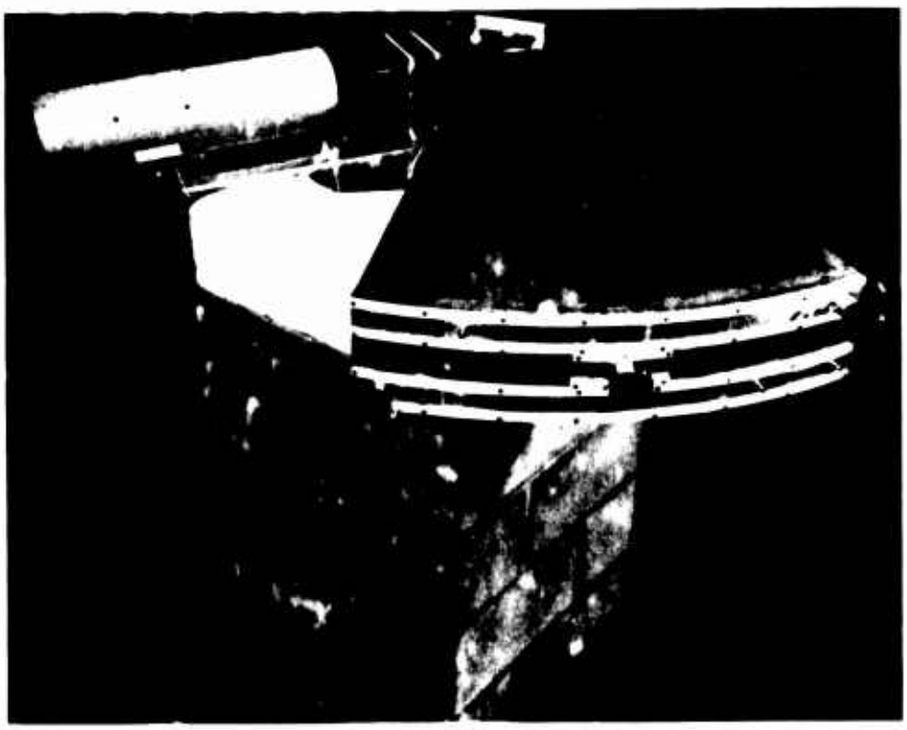

FIGURE 3. PHOTO OF IMAGE ORTHICON SPECTROGRAPH

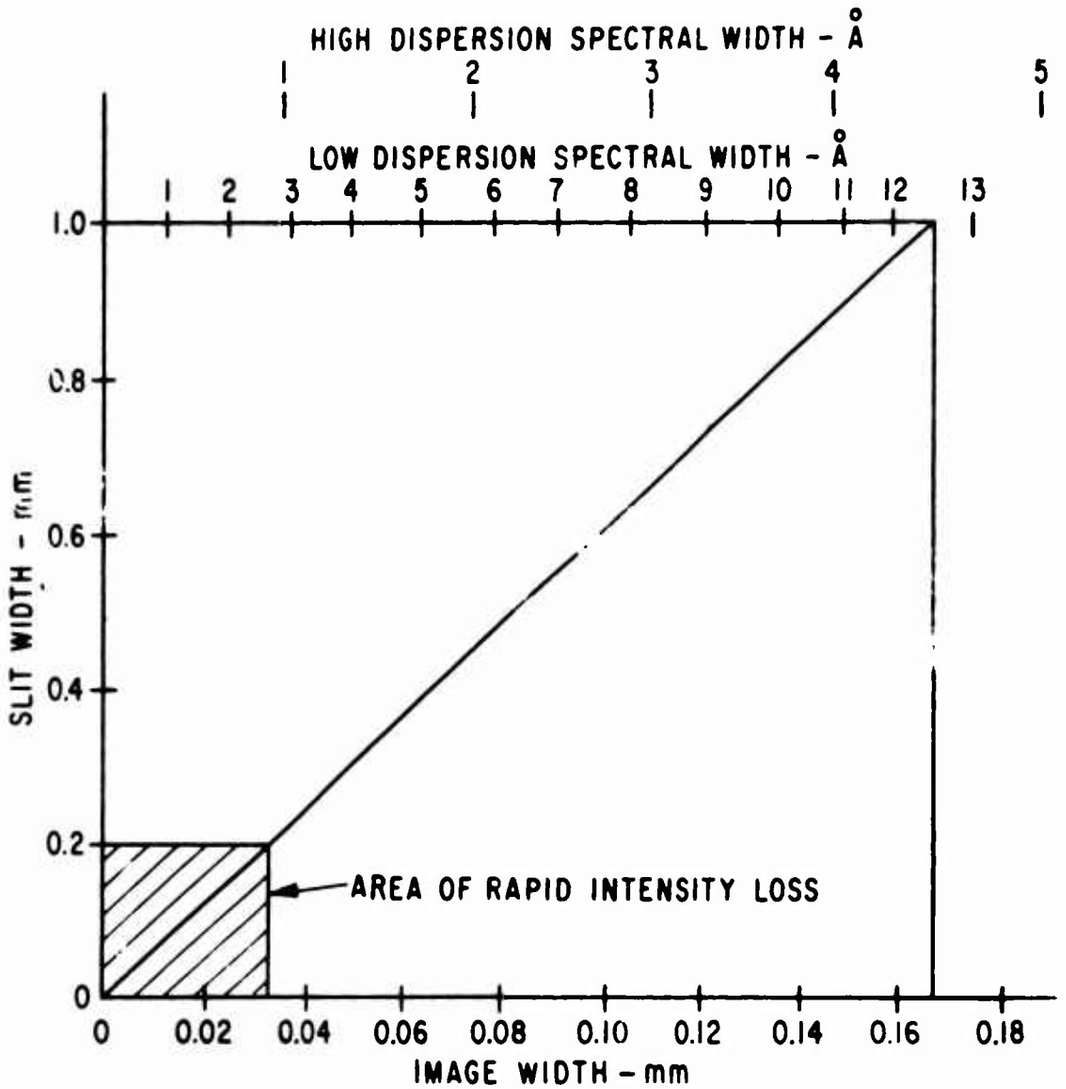

Figure 4. Measured Image Width vs. Slit Width for a High Dispersion 2160 groove/mm and a Low Dispersion 600 grove/mm Grating on the Three Slit Spectrograph

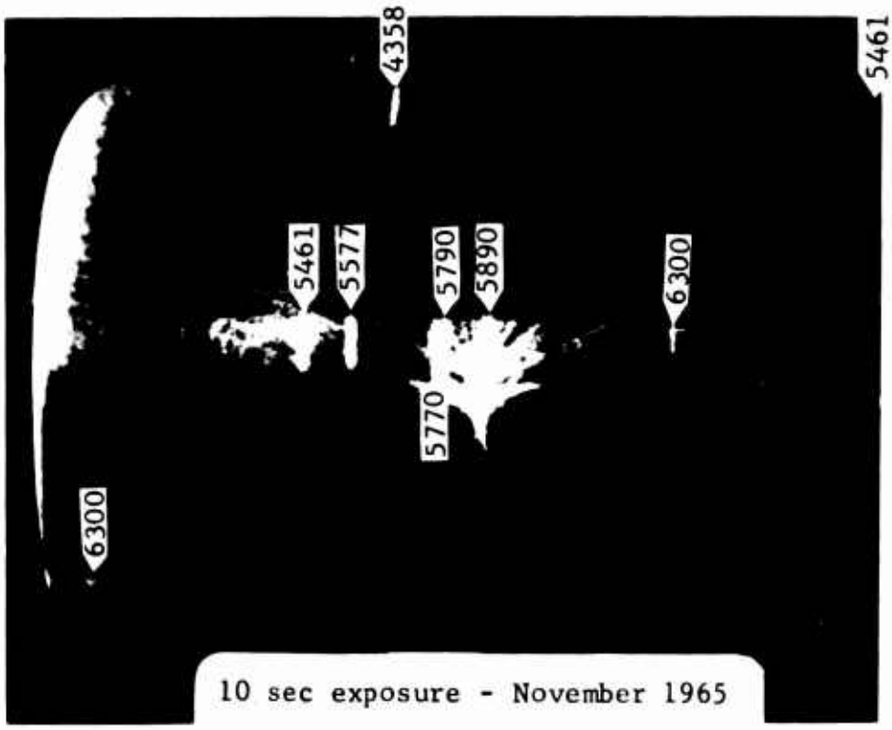

Figure 5 Typical Night Air Glow Photo

10 sec exposure on the image orthicon target,
one readout frame on the film

of Aerospace Research, USAF, under Contract AF19(628)-2366, Project Nos. 8653 and 7661 with the General Electric Company.

REFERENCES

1. J. F. Spalding & C. L. Hemenway, Astron. J. 66, 54 (1961).

2. G. T. Hicks & T. N. Davis, Geophys. Res. 69, 1931 (1964).

3. G. T. Hicks & T. N. Davis, Appl. Opt. 4, 187-188 (1965).

4. J. W. Chamberlain, "Physics of the Aurora and Air Glow" (Academic Press Inc., New York, 1961) Rayleigh defined p. 569-570.

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13. ABSTRACT

During 1964-65 a continuing investigation was performed to examine the feasibility of obtaining information on the time-changing characteristics of the aurora and night air glow by low-light level image orthicons at the Radio-Optical Observatory of the General Electric Company's Research & Development Center in Schenectady, New York. Although no auroras were detected during this interim period, wavelength and intensity calibrations on a spectrograph of special design using the image orthicon detector were accomplished with spectral lamps and night air glow emissions. Included spectral photographs of night air glow demonstrate that the image orthicon is at least 1000 times faster than photographic film when detecting weak "point" or "line" sources under high contrast conditions. Twenty photoelectrons are sufficient to record a spectral line. Sensitivity calibrations were also performed on a 16" f/20 telescope, where the North Polar Sequence of Stars provided a standard calibrated star field. Within 10 seconds, 18th magnitude stars were detected.

Further analysis is given on the data recorded during the September 1963 aurora and initially reported in the Final Report of Phase I, 1963 - AFCRL 64-209.

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14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
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Auroras	8	1				
Night Air Glow	8	2				
Image Orthicons (I.O.)	8,4	3				
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