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PHOTOMETRIC AND INTERFEROMETRIC OBSERVATIONS OF A MID-LATITUDE STABLE AURORAL RED ARC

R. G. ROBLE, P. B. HAYS and A. F. NAGY
The University of Michigan, Ann Arbor, Mich. 48105, U.S.A.

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Abstract—Observational results of the mid-latitude stable auroral red arcs of October 30/31 and October 31/November 1, 1968 are presented. The measurements were made with a turret photometer and a 6 in. dia. high resolution, pressure scanning Fabry–Perot interferometer. The structure, intensity, and position of the red arc were determined from photometer scan measurements which show that the arc was stable, persisted for more than 12 hr, and moved southward during the night. The arc appeared to extend across the eastern part of the United States tilted to lines of constant magnetic L-shells. The results of the Doppler temperature measurements made with the Fabry–Perot interferometer show no measurable neutral gas temperature increase within the red arc.

1. INTRODUCTION

The mid-latitude stable auroral red arc was discovered by Barbier (1958) at times of geomagnetic disturbances during the last solar cycle maximum. The observed properties of the arcs, which occurred during the last solar cycle maximum, have been summarized by Roach and Roach (1963) and Marovich (1966). Hoch, Marovich and Clark (1968) and Ichakawa and Kim (1969) have reported on the reappearance of the stable auroral red arc for the current solar cycle maximum. Most of the observations made previously on the red arc have been photometric measurements. This paper summarizes the observed properties of the mid-latitude stable auroral red arcs of October 30/31 and October 31/November 1, 1968 determined by a turret photometer and a high resolution Fabry–Perot interferometer. The measurements were made from the University of Michigan Airglow Observatory at Ann Arbor Michigan (42°16′N, 83°44′W).

The turret photometer is of the type designed by Purdy, Mcgill and Roach (1961) and modified by Roble (1969); it was used to monitor the 5577 and 6300 Å atomic oxygen emission lines and the 5400 and 6100 Å continuum regions. In addition to the turret photometer a 6 in. dia., high resolution pressure scanning Fabry–Perot interferometer was used to measure the Doppler temperature of the $[O(^1D) \rightarrow O(^3P)]$ 6300 Å atomic oxygen line. Both instruments have mirror scanning systems in order to scan in various sky positions. The details of the instruments are described elsewhere (Roble, 1969; Hays, Nagy and Roble, 1969); only the observational results are reported in this paper.

2. THE STABLE AURORAL RED ARC OF OCTOBER 30/31, 1968

A large geomagnetic storm, as revealed by the increased magnetic index, K_p, shown in Fig. 1, began at about 0000 UT on October 31, 1968, and both the Fabry–Perot interferometer and the airglow photometer were making nightglow measurements at that time. The early evening records gave some indication of an arc type enhancement at an approximate zenith angle of 30° north of the geophysical observatory; however, it was not possible to resolve the feature completely because of some clouds in the area. No measurements were made from 0200 to 0545 UT because of cloudy conditions, but a general clearing occurred near 0600 UT and a small (100 R) red arc was observed from Ann Arbor at a zenith angle of approximately 50° south in the meridian plane. The photometer mirror

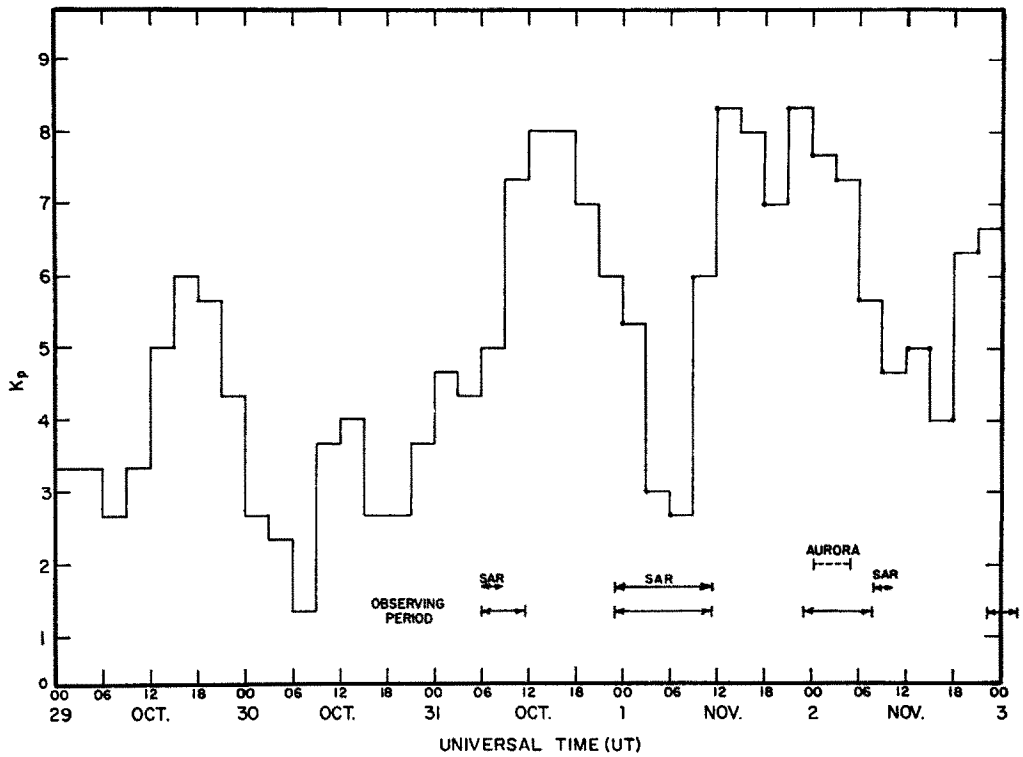

FIG. 1. THE MAGNETIC INDEX K_p AS A FUNCTION OF TIME FOR THE DISTURBED PERIOD OCTOBER 30–NOVEMBER 2, 1968.

system was performing a North–South vertical circle scan and the red arc appeared as a distinct enhancement of the 6300 Å emission at 50°S which was superimposed upon the normal Van Rhijn intensity variation. At the same time, there was a noticeable increase in the 6300 Å emission line in the North which was probably related to auroral activity. No enhancement, in the red arc region, was evident from either the 5577 or 6100 Å photometer scans. The arc moved slowly southward 5 to 10 deg and persisted until 0715 UT when it disappeared. At 0837 UT the 6300 Å emission again increased in the North; however, the red arc did not reappear. The doppler temperature measurements made during the night are shown in Fig. 2 where they are seen to remain nearly constant throughout the night at 1000°K. The red arc persisted at a time when the K_p index was increasing and disappeared even though K_p continued to increase during the night.

3. THE STABLE AURORAL RED ARC OF OCTOBER 31/NOVEMBER 1, 1968

The magnetic storm which started on the night of October 30/31, 1968, continued during the next day, reaching a K_p value of 8 near 1200 UT on October 31, as shown in Fig. 1. The storm then decreased in intensity and a red arc was detected south of Ann Arbor shortly after sunset and it persisted throughout the night. Figure 3 shows the position of the peak intensity in the meridian plane from the airglow observatory. At 0030 UT the arc was clearly defined to be at a zenith angle of 15° south in the meridian plane. Between 0000 and 0300 UT on November 1, the red arc moved southward with a speed of about 40 m sec^{-1}, when the speed is calculated at 400 km, the assumed red arc height. The arc

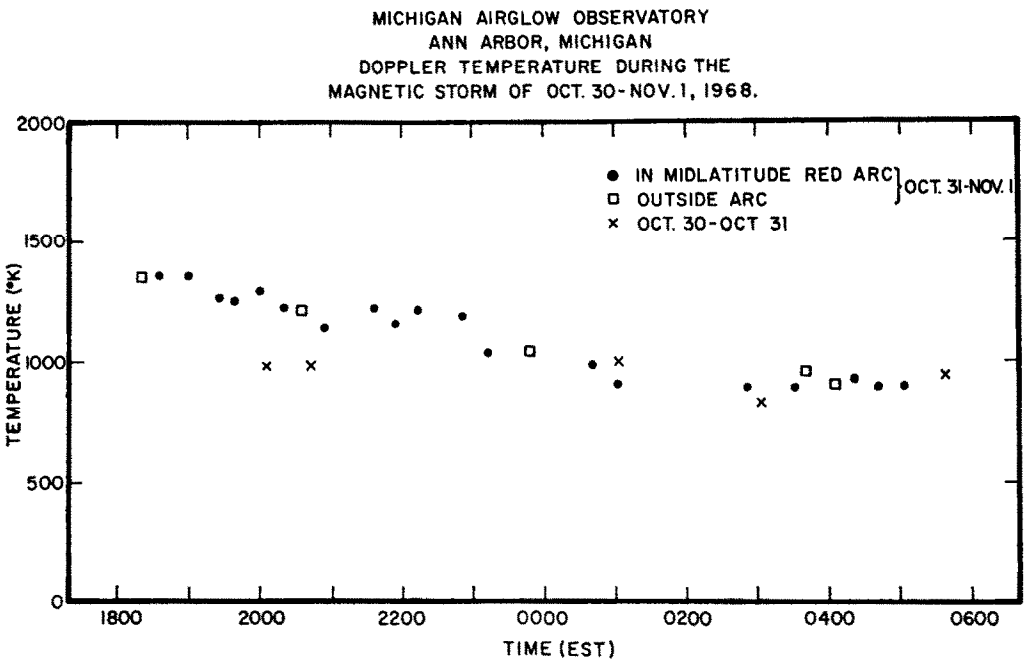

FIG. 2. 6300 Å DOPPLER TEMPERATURE MEASUREMENTS DURING THE MAGNETIC STORM OF OCTOBER 30–NOVEMBER 1, 1968.

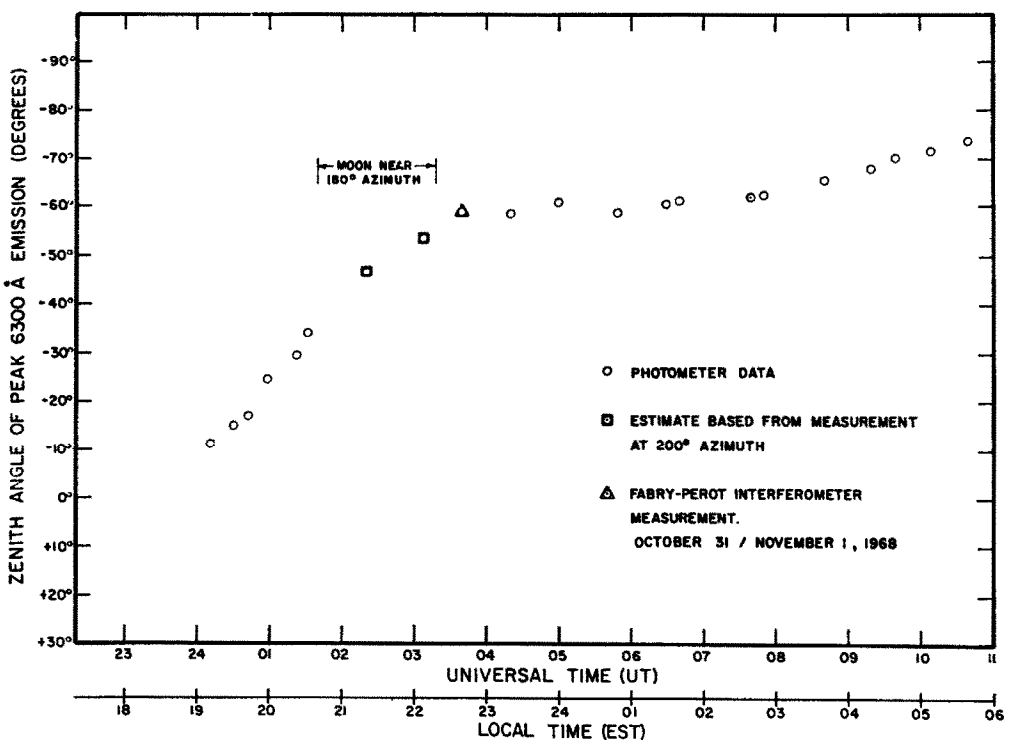

FIG. 3. ZENITH ANGLE OF THE PEAK 6300 Å INTENSITY IN THE MERIDIAN PLANE OF THE AIRGLOW OBSERVATORY AS A FUNCTION OF TIME DURING THE NIGHT OF OCTOBER 31–NOVEMBER 1, 1968.

settled at a zenith angle near 60°S and remained at that position until 0800 UT at which time the arc began moving southward again at a speed of approximately 40 m sec^{-1}.

Vertical circle surveys were performed with the photometer after the initial location of the red-arc in order to define the horizontal position and extent of the arc. The mirror scanning system was first positioned in azimuth and maintained at that position while a vertical circle scan was performed; going from +80° zenith angle in the North through the zenith to −80° zenith angle in the South. The mirror was then positioned to a new azimuth angle, usually 20° from the previous position, and the scan was repeated. Typical scan sequences using the 6300, 6100 and 5577 Å filters in the airglow photometer are shown in Figs. 4, 5 and 6. The red-arc appears on the 6300 Å results as a distinct enhancement, superimposed on the normal Van Rhijn intensity increase near the horizon.

The sky conditions during the entire night of October 31/November 1 were generally clear but with some Autumn haze which persisted throughout the night. In addition, a near full Moon was present in the southern sky until about 0730 UT. The Moon's presence is evident in Figs. 5 and 6 which show the 6100 and 5577 Å photometer scans respectively. The increased intensity in the southern sky is caused by the Moon; however, the sharp intensity enhancement evident in the 6300 Å filter scan is not present at the other wavelengths indicating that the arc is a region of predominantly 6300 Å enhancement. Scans of this type, using the 5400, 5577, 6100 and 6300 Å filters in the turret photometer, were made throughout the night and only the 6300 Å scans showed the characteristic enhancement, revealing the presence of a red-arc.

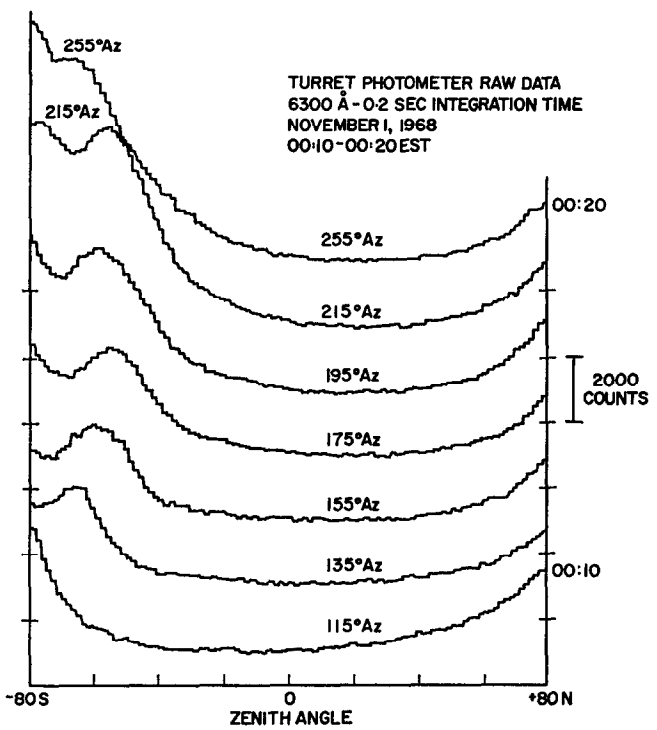

FIG. 4. 6300 Å VERTICAL CIRCLE SCANS WITH THE TURRET PHOTOMETER AT 0010–0020 EST ON NOVEMBER 1, 1968.

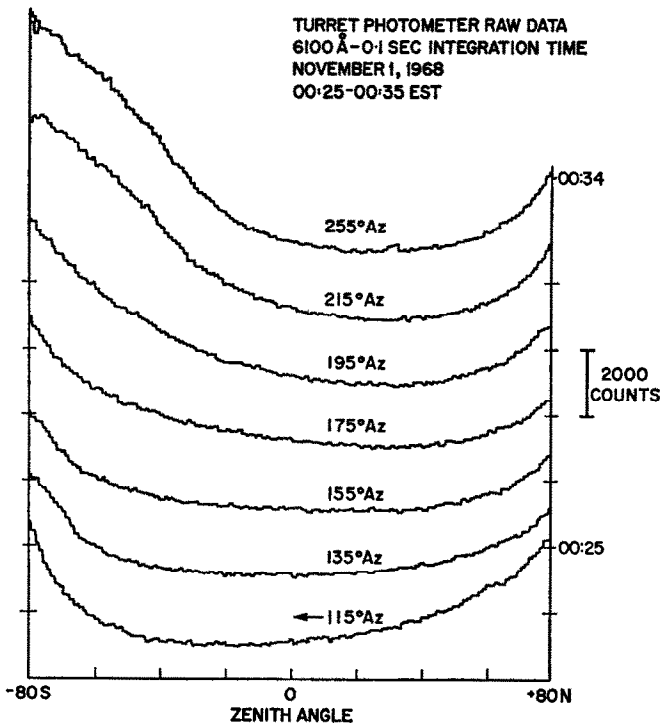

FIG. 5. 6100 Å VERTICAL CIRCLE SCANS WITH THE TURRET PHOTOMETER AT 0025–0035 EST ON NOVEMBER 1, 1968.

The Fabry–Perot interferometer was primarily used for Doppler temperature measurements; however these measurements were, at times, interrupted in order to use the interferometer as an extremely narrow interference filter and perform a zenith scan. The interferometer was positioned and maintained on the 6300 Å fringe peak while the mirror scanning system operated in a North–South vertical circle scan crossing the red arc region. The results of the scan are shown in Fig. 8, where the enhanced 6300 Å emission of the SAR-arc clearly stands out. After the scan was completed, the interferometer was moved 0·1 Å off of the fringe peak, beyond the wings of the doppler emission line, in order to measure the nearby background. A vertical scan of the interferometer in this position revealed no noticeable enhancement of the background near 6300 Å where the SAR-arc was present. The same measurement was also performed using the 5577 Å green line filter in the interferometer and the results do not show a characteristic enhancement in the arc region indicating that the major emission within the arc is the 6300 Å radiation of atomic oxygen.

The horizontal extent of the red-arc relative to the airglow observatory at Ann Arbor was determined from these figures and the results are shown in Fig. 7, where the peak 6300 Å intensity position is located on an auroral plotting map at various times. In order to position the arc on the map, the height of the peak emission was assumed to be 400 km which is consistent with the theoretical calculations of Walker and Rees (1968) and Roble (1969) and the results of numerous observations (Roach and Roach, 1963; Rees, 1963; Hoch, Marovich and Clark, 1968).

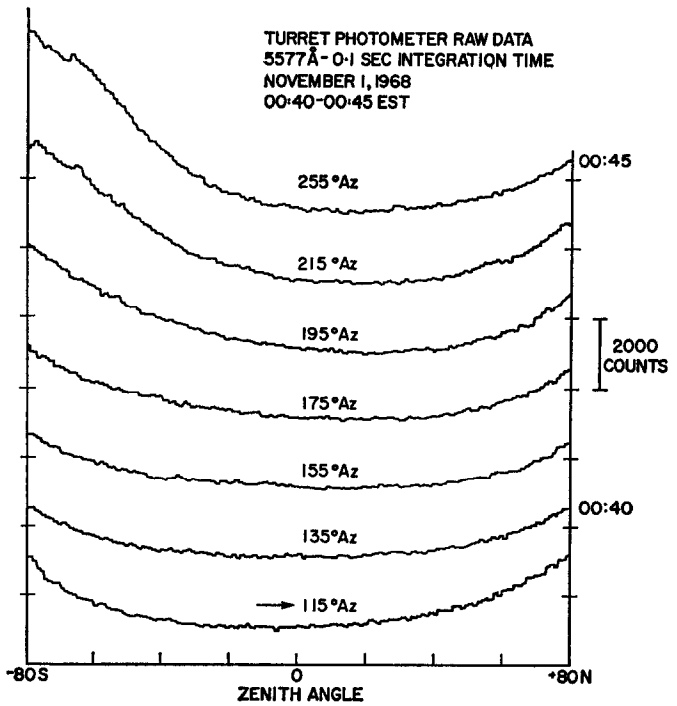

FIG. 6. 5577 Å VERTICAL CIRCLE SCANS WITH THE TURRET PHOTOMETER AT 0040–0045 EST ON NOVEMBER 1, 1968.

The red arc is seen to lie approximately along constant L-shells, although there appears to be a slight departure from true alignment. This result is in agreement with observations reported by Hoch, Marovich and Clark (1968). The red-arc was observed to extend across the eastern U.S., and exhibited a general southward motion throughout the night. The southward drift was associated with both increasing and decreasing K_p. The red arc position, as determined by Marovich (private communication) from Fritz Peak at 0950 UT, is shown as a dotted line, and when it is considered together with the arc positions determined by the Michigan Airglow Observatory at Ann Arbor, the red-arc is seen to extend across the entire U.S.

The intensity of the arc varied throughout the night, ranging from 100 to 600 R and there also appears to have been some intensity variations along the length of the arc. The intensity was about 300 R at 0130 UT and increased until it reached a maximum of about 600 R near 0515 UT. The intensity then decreased to 300 R at 0830 UT and shortly before dawn at 0945 UT it was about 100 R or less and the arc was low on the southern horizon. It is not clear to what extent the signal was attenuated by the haze conditions existing near the southern horizon. In the early part of the evening there is also evidence of an enhancement in the North which is probably due to auroral background, although no visual sighting of an aurora was made during the night. The general airglow background appeared to have been slightly enhanced from normal conditions in the early evening but it decayed to about 100 R at 0515 UT and then remained nearly constant for the remainder of the night.

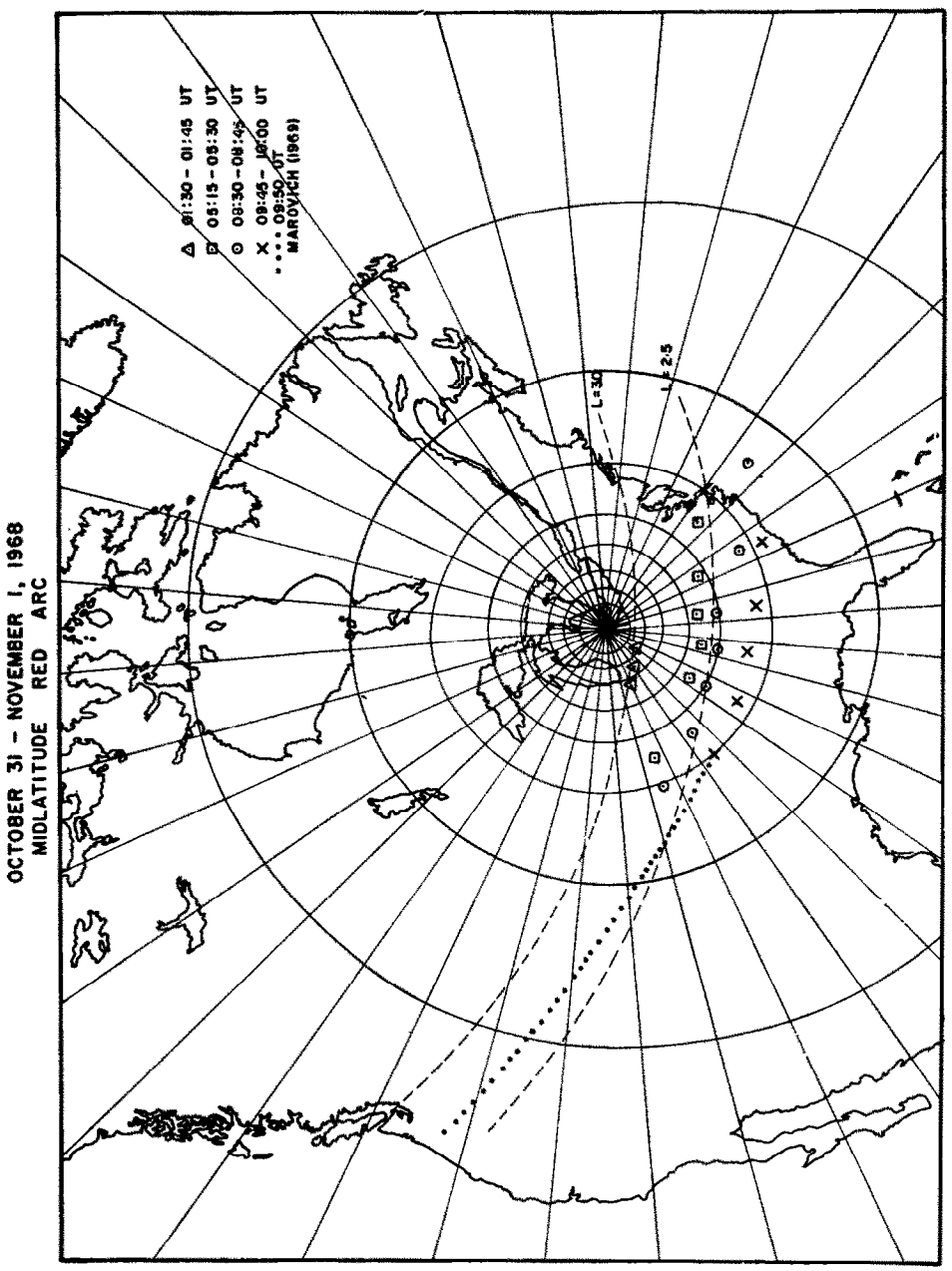

FIG. 7. GEOGRAPHIC POSITION OF THE RED ARC OF OCTOBER 31–NOVEMBER 1, 1968 DETERMINED FROM THE AIRGLOW OBSERVATORY; THE DOTTED LINE INDICATES THE POSITION OF THE RED ARC AT 0950 UT DETERMINED FROM FRITZ PEAK, COLORADO (MAROVICH, PRIVATE COMMUNICATION).

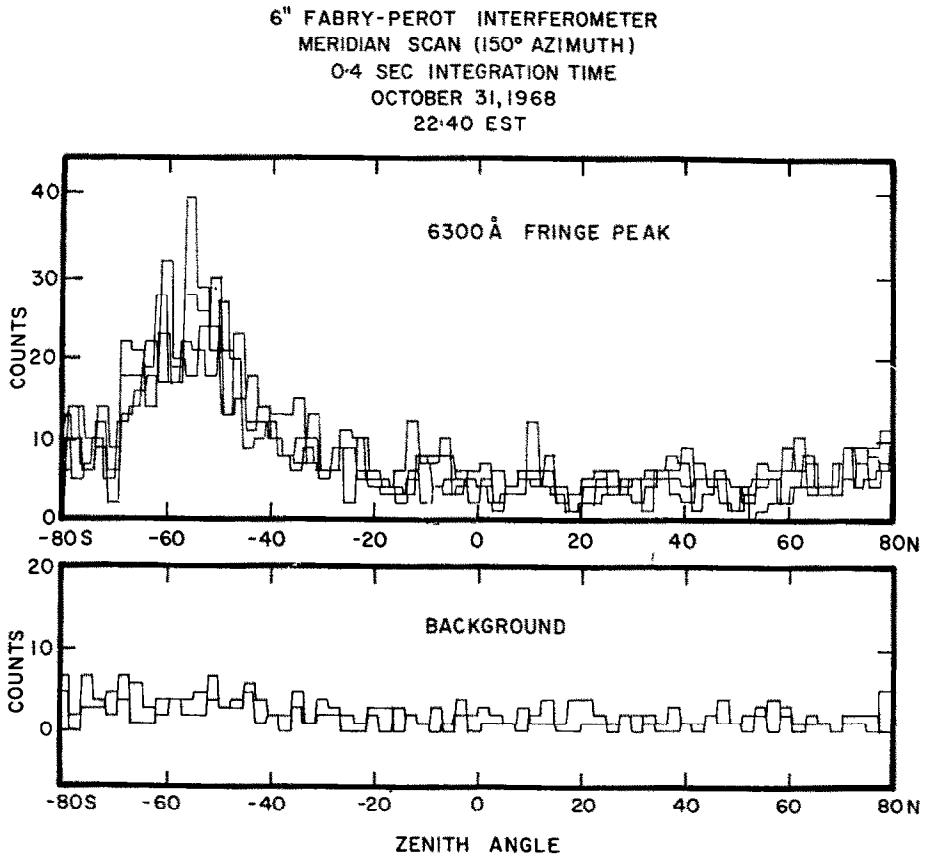

FIG. 8. FABRY–PEROT INTERFEROMETER VERTICAL CIRCLE SCAN AT 0340 UT, OCTOBER 31, 1968.

The Doppler temperatures within and outside of the arc region and the exospheric temperature variation during the magnetic storm period were measured with the Fabry–Perot interferometer (Hays, Nagy and Roble, 1969). The doppler temperatures measured during several nights of this magnetic storm were in general agreement with the model predictions of the exospheric temperature (Jacchia, 1965). However, both the amplitude and phase of the doppler temperatures indicated that the exospheric temperature responds more rapidly than the drag results suggest. The Doppler temperature measurements inside and outside of the arc region (Fig. 2) showed no detectable temperature variation, indicating that the neutral gas temperature increase within an arc is negligible. This result is in agreement with the theoretical studies of Roble (1969) on the local heating and subsequent dynamic response of the atmosphere, which showed that the neutral atmosphere reacts to prevent the development of a significant steady state local temperature anomaly in a red arc. Walker and Rees (1968) have shown that if electric fields are the cause of red arcs, the F_2 ion-temperatures would be in excess of 5000°K. Such high ion temperatures would effect the neutral gas temperatures, therefore lack of Doppler temperature increase inside the arc could be considered as an indirect evidence against the electric field hypothesis.

4. SUMMARY

The results of the observations described in this paper are summarized below:

(1) Red arcs were observed to be present during two consecutive nights of a magnetic storm period ($3 < K_p < 8$).

(2) The arc of October 31–November 1 was observed across the entire U.S. The arc was approximately aligned with a constant L-shell, although a slight departure from true alignment was apparent; this may indicate a distortion of the L-shells during a magnetic storm.

(3) The intensity of the arc varied throughout the night between 100 and 600 R. The predominant emission was 6300 Å, and no 5577 Å enhancement was apparent within the arc.

(4) The arc of October 31–November 1 moved southward with a velocity of about 40 m sec^{-1} during the early night and late morning hours but appeared to be stationary during the middle of the night.

(5) The Doppler temperature observations indicated no temperature increase inside the arc in agreement with theoretical predictions. This result is also an indirect indication that thermal conduction from the protonosphere is the likely source of red arc excitation (Cole, 1965).

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