THE ZONE OF HYDROGEN EMISSION IN THE NIGHT SKY

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Summary

Measurements of hydrogen emission made at the Australian National Antarctic Research Expedition's station at Mawson, and the New Zealand Antarctic stations at Scott and Hallett in Antarctica are used to determine the location and behaviour of the hydrogen emission zone in the southern hemisphere. The intensity of the emission varies greatly with the 11 year solar cycle. The magnetic dependence of the hydrogen emission is discussed.

I. INTRODUCTION

The visual aurora is a striking phenomenon that has been observed for centuries and in 1837 (Chamberlain 1961) it was realized that visual auroras occurred in zones. Most work has been based on northern hemisphere data and it is only recently that the location of the southern auroral zone has been clearly defined (Bond and Jacka 1962; Feldstein and Solomatina 1962; Sandford 1964). During and since the IGY particularly, the night sky has been studied extensively with photometers and spectrographs, leading to the discovery of types of non-visual aurora (Sandford 1964) that behave very differently from the visual aurora. One phenomenon in this class is the hydrogen emission.

Various workers in the northern hemisphere have established that there is a zone of hydrogen emission. Montalbetti and McEwen (1962) used a scanning spectrophotometer to measure the diurnal behaviour of hydrogen emission at Churchill and found an association between hydrogen emission and "*r*" type sporadic *E* ionization. A similar relationship was found at College. They used these results with the information on *r* type sporadic *E* from Baker Lake and Winnipeg to determine a hydrogen emission zone for the northern hemisphere.

Using hydrogen emission observations from Murmansk, Churchill, College, and Tixie Bay (stations well separated in longitude) for the night of February 10–11, 1958, Yevlashin (1963) found that the hypothesis of a broad ringlike zone of hydrogen emission, shifting in space as a single whole, was confirmed.

Measurements with an Hβ scanning photometer at Mawson (geographic coordinates 62·9° E., 67·6° S.; eccentric dipole latitude $\theta = 71°$) and patrol spectrographs at Scott (166·8° E., 77·9° S.; $\theta = 79°$) and Hallett (170·2° E., 72·3° S.; $\theta = 76°$) are used in the present paper to determine an average hydrogen emission zone for the southern hemisphere, the intensity variations of hydrogen emission with the solar cycle, and the magnetic dependence of the hydrogen emission.

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In the analysis the geographic latitude and geographic time of the stations were found to be not very useful parameters. The geomagnetic coordinates were found to be more useful, but the best consistency was obtained when the eccentric dipole latitude and eccentric dipole time (Cole 1963) were used.

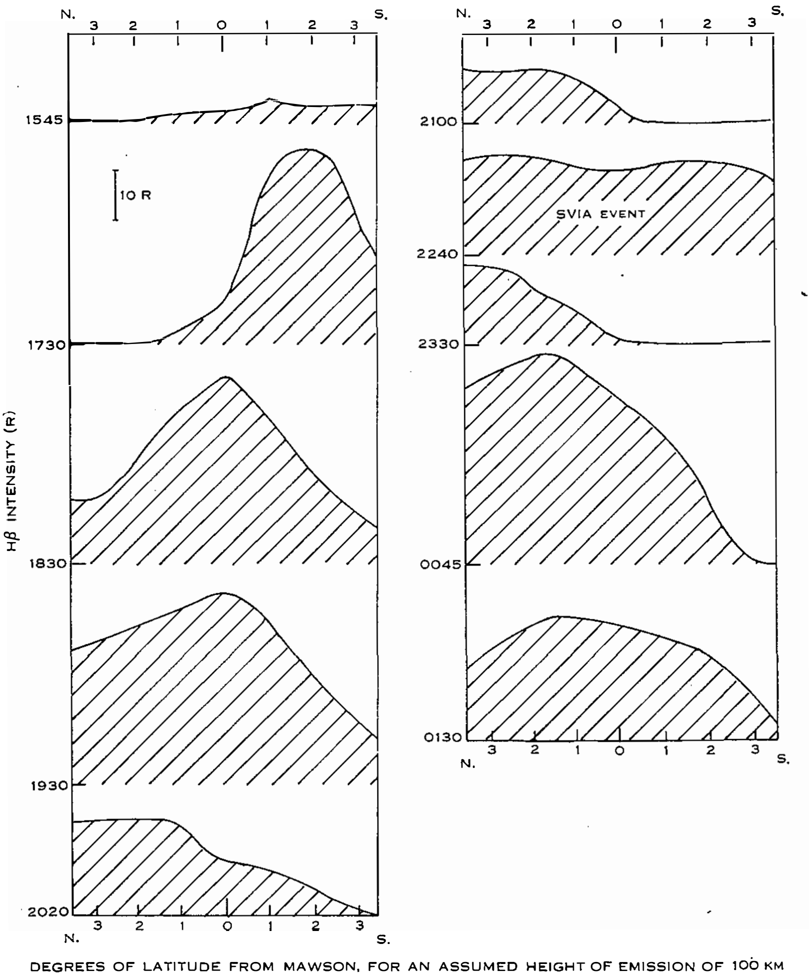

Fig. 1.—A set of scans, along a meridian, of the hydrogen emission from Mawson on a typical night in 1963.

II. Observations and Results

The scanning photometer used at Mawson during 1963 had a sensitivity of 1 R (1 rayleigh = 10^6 photons cm^{-2} column s^{-1}) and used a tilting multilayer interference filter with a half-transmission bandwidth of 3 Å to isolate the Hβ line. This instrument will be described in detail by Eather and Jacka (1966*b*). The typical average diurnal behaviour of the hydrogen emission observed from Mawson was as follows. Early in the night about 1500–1600 EDT (EDT = eccentric dipole time $\approx$

universal time plus 1 hr 40 min ≈ Mawson local time less 2 hr 30 min) the maximum of the hydrogen emission was located well to the south of Mawson. The region of maximum emission gradually moved north and passed overhead at about 1900–2000 EDT, reaching the region of the northern horizon from Mawson at about 2100 EDT. Sometimes the maximum of the emission stayed in this position but at other times it appeared to move over the northern horizon. The hydrogen emission often spread back and covered the sky at about 2200–2400 EDT, accompanied by slowly varying ionospheric absorption (SVIA), which was measured on a riometer

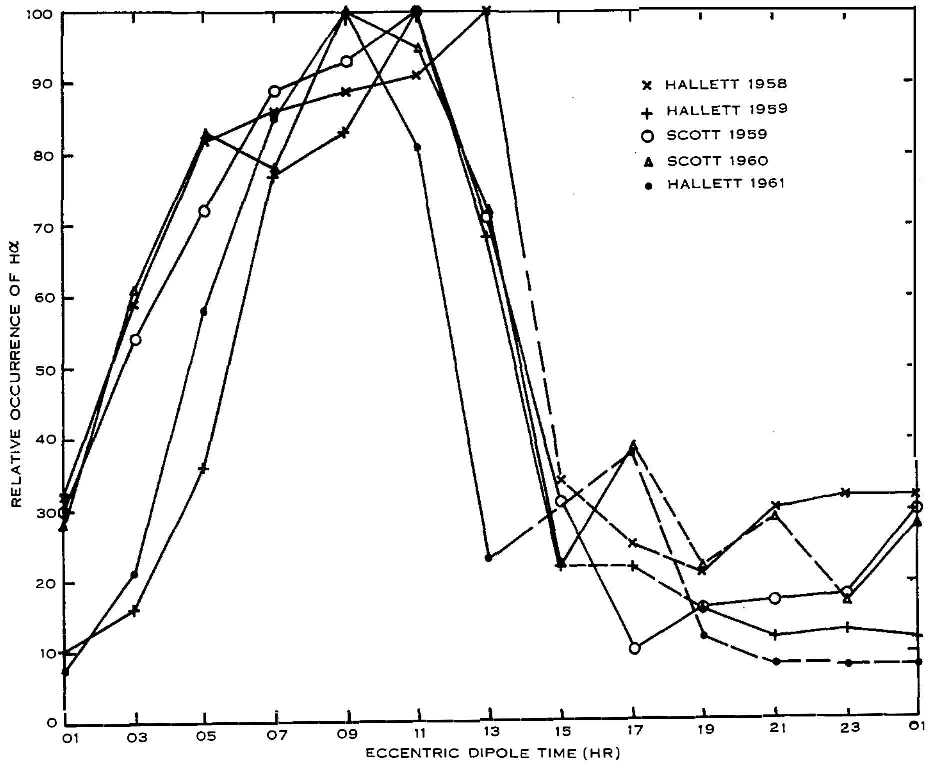

Fig. 2.—The diurnal occurrence of hydrogen emission from Scott and Hallett stations, 1958–61. The curves are normalized with the maximum occurrence each year equal to 100%.

(Eather and Jacka 1966*a*). After the SVIA events the emission maximum moved north again, where it often remained until twilight stopped observations at about 0400 EDT. Sometimes, after 0100 EDT the maximum started to move back southwards and was located in the zenith by 0400 EDT.

A set of scans along the eccentric dipole meridian on a typical night is shown in Figure 1. Unfortunately the technique of scanning the sky with the Hβ photometer did not allow a statistical average curve for the occurrence of Hβ in the zenith to be determined.

The patrol spectrographs (Devlin, Oliver, and Carrigan 1964) used at Scott, 1959–61 and 1963, and at Hallett, 1957–61 and 1963, had a sensitivity of about 200 R at the wavelength of Hα with the normal exposure time of 100 min. (Note that Hβ was measured at Mawson and Hα was measured at Scott and Hallett. The intensity of Hβ is normally between one-half and one-quarter the intensity of Hα.) Each day was divided into 2 hr intervals at each even hour of the day. For each 2 hr interval, the number of days on which Hα was observed, as a percentage of the total number of days on which the spectrograph operated, was obtained. Only times when the solar depression was greater than 9° were used. These percentages were then normalized

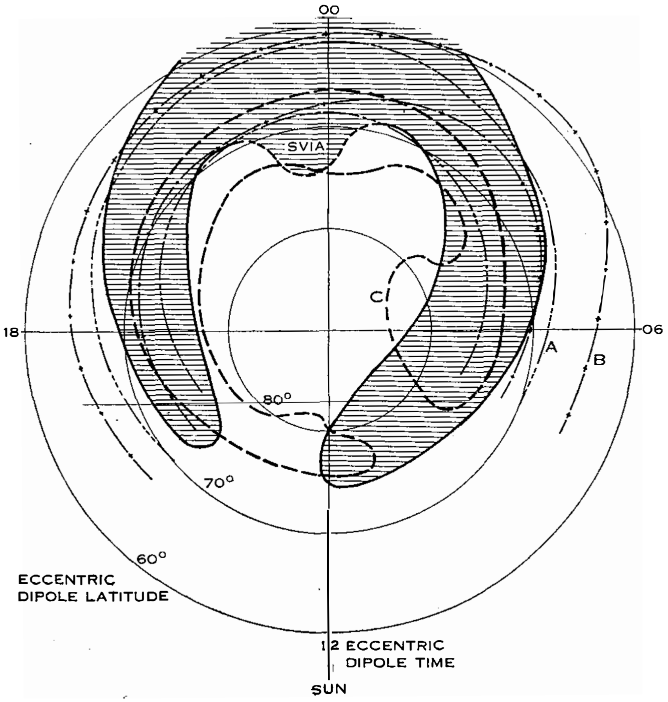

Fig. 3.—The zone of hydrogen emission in the southern hemisphere as a function of eccentric dipole latitude and eccentric dipole time. For comparison the conjugates of the northern hemisphere hydrogen emission zones of Montalbetti and McEwen (1962), curve A, and Yevlashin (1963), curve B, and the southern hemisphere zone of maximum visual auroral occurrence of Sandford (1964), curve C, are shown.

so that the maximum percentage of occurrence was made equal to 100%. Spectra taken in the presence of moonlight or cloud were not excluded because a check of the years when this could be done gave the same answers for both cases. The results, shown in Figure 2, give the shape of the diurnal curves of the Hα occurrence, but not their relative amplitudes, for the years in which sufficient observations were made to give reliable data. The curves do not vary significantly from year to year, suggesting that the shape of the hydrogen emission zone does not vary to any great extent over the solar cycle. The data used here are from the whole of each spectrum, which is recorded from a strip of sky through the zenith and down to each horizon. From both

Scott and Hallett the shape of the diurnal curves was the same when the data were taken either from a point at 10° elevation above the northern horizon or from a point at 10° elevation above the southern horizon; however, the intensity of the hydrogen emission was almost always at least three times more intense to the north than to the south at each station.

From the photometric observations at Mawson and the spectrographic observations at Scott and Hallett, it was possible to determine an average southern hemisphere zone of hydrogen emission (Fig. 3) that fits the observational data, assuming that the Earth rotates below a zone fixed with respect to the Sun and the pole of the

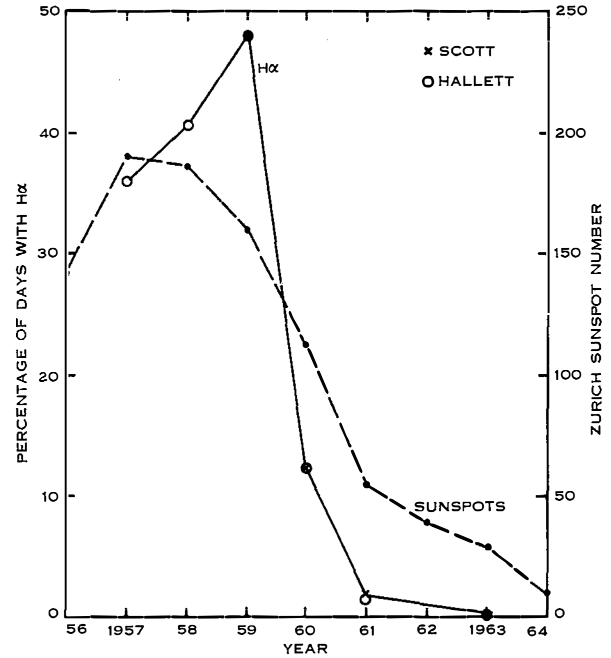

Fig. 4.—The annual occurrence of hydrogen emission from Scott and Hallett stations, 1957–63, and the Zurich relative sunspot numbers.

eccentric dipole. Little success was obtained in consistency between the observations until eccentric dipole coordinates were used. Clearly more data from stations well distributed in latitude and longitude would be necessary to determine the shape of the zone with any more certainty. Perhaps the zone bulges out at low latitudes after midnight, similarly to that of the visual auroral zone (Sandford 1964).

The zones of hydrogen emission obtained by Montalbetti and McEwen (1962) and Yevlashin (1963) in the northern hemisphere were converted to eccentric dipole coordinates and the conjugates of these zones are plotted in Figure 3. The zone of Montalbetti and McEwen agrees very well with the southern hemisphere zone. Yevlashin's zone does not agree so well but it is based on data from only one night, which was very disturbed magnetically. It seems reasonable to conclude that the northern hemisphere and southern hemisphere hydrogen emission zones are conjugate in the eccentric dipole field.

In Figure 3, the region of maximum occurrence of visual aurora from Sandford (1964) is also shown. (Note that Sandford's auroral latitude is almost identical with eccentric dipole latitude.) The zone of hydrogen emission lies equatorward of the visual auroral zone, which is in accordance with the observations of many workers. It is interesting that both zones have a region of low occurrence near noon, the visual aurora having a minimum occurrence before noon and the hydrogen emission showing

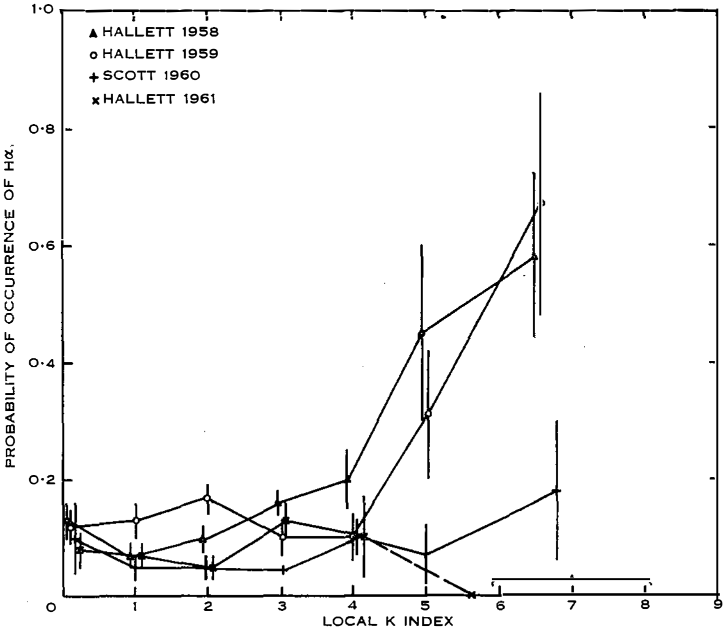

Fig. 5.—The probability of occurrence of hydrogen emission as a function of local magnetic K index for Scott and Hallett stations, 1958–61.

a minimum occurrence after noon. This is suggestive of a drift phenomenon where the negative electrons producing visual aurora and the positive protons producing hydrogen emission drift in opposite directions in the Earth's magnetic field. Both zones tend to approach the pole in the morning hours, which is suggestive of a common influence, possibly like magnetic convection as in the theory of Axford and Hines (1961).

In order to try to obtain a measure of the relative amplitude of the diurnal variation from year to year, the total number of days on which Hα was observed as a fraction of the number of days on which the spectrograph operated is shown for each year in Figure 4. The Hallett spectrograph in 1957–59 was less sensitive than the Scott spectrograph, so these Hallett data have been normalized to the Scott 1959 value. The Hallett spectrograph was modified extensively and was much faster than the Scott instrument after 1960, so for these years Hallett data are normalized to Scott 1960. In Figure 4 the annual occurrence of Hα is seen to vary considerably; this is possibly caused by the 11 year cycle of solar activity, which is also shown in the figure. The peak year of hydrogen emission is 1959, between 1 and 2 years after the sunspot maximum of late 1957. This is similar to the peak of visual auroral occurrence which Meinel, Negaard, and Chamberlain (1954) found to occur 2 years after sunspot maximum. Gartlein (1952), from a limited amount of data, has also noted a solar cycle variation of hydrogen emission at Ithaca, New York.

Figure 4 indicates only that the daily occurrence of hydrogen emission appears to change from year to year. An examination of intensity measurements suggests that this is due to changes in the intensity from year to year, the intensity falling below the sensitivity of the spectrographs in the years of sunspot minimum. The Hβ emission recorded at Mawson on most nights in 1963 near sunspot minimum had an intensity of less than 50 R, which corresponds to an Hα intensity at the limit of sensitivity of the spectrographs. On the other hand, Montalbetti (1959) found that the intensity of Hβ at Churchill near the time of the sunspot maximum was of the order of hundreds of rayleighs.

The relationship between magnetic disturbance and the occurrence of hydrogen emission at Scott and Hallett is shown in Figure 5 for the years 1958–61, the only years with sufficient sample size. The probability of observing hydrogen emission at any time during the 3 hr interval over which the local K index of magnetic activity was measured is given along with the standard deviations (due to sample size only). Up to a local K index of 4, the occurrence of hydrogen emission is roughly constant at 5–15%. During disturbed periods when the K index is 5 or greater there is a strong dependence on magnetic activity in 1958 and 1959, years of high solar activity. In 1960 the dependence has fallen considerably but the occurrence may increase at higher K indices. In 1961 there are insufficient incidences of K index greater than 4 to give reliable data. During disturbed magnetic conditions there seems to be a dependence on magnetic activity, which is strongest at times of maximum solar activity.

The data were also plotted against the world-wide magnetic activity using the planetary K index. The dependence was less obvious in this case, showing that hydrogen emission is more closely associated with local disturbance than with planetary disturbance. It was thought that energetic protons from solar flares, which are frequent only at times of maximum solar activity, might explain the dependence when the magnetic activity is high. Data were replotted after removing times during which polar-cap absorption events (PCA) occurred (Bailey 1964), but this had no effect on the shape of the curves. It has been shown by Sandford (1963) that even during an intense PCA event the intensity of the Hβ emission caused by the energetic solar protons would rarely exceed 100 R. Hence hydrogen emission from this cause would only be observable in the greatest events, and then only at the peak of the event, on the spectrographs used at Scott and Hallett. The high intensities of hydrogen emission observed during large magnetic storms therefore do not arise from the energetic protons that give rise to PCA events.

These observations were made at a much higher latitude than those of other workers. Montalbetti and Vallance-Jones (1957) observed a negative correlation with local magnetic activity in 1955–56 at Churchill, just before a solar maximum. They and other workers (Gartlein 1952; Galperin 1959; Malville 1959; Rees, Belon, and Romick 1961; and Yevlashin 1963) observed a positive dependence of hydrogen occurrence on local magnetic activity at eccentric dipole latitudes of less than 67°. This has generally been interpreted as due to an expansion to lower latitudes of the equatorward side of the hydrogen emission zone as magnetic activity increases, rather than to an increase in occurrence of hydrogen emission. There are unfortunately practically no results available on the relationship between magnetic activity and the absolute intensity of hydrogen emission. Absolute intensity measurements at a series of stations about 5° apart along a meridian would be necessary to establish the real relationship between hydrogen emission and magnetic activity.

III. Conclusions

There is a zone of hydrogen emission which lies about 5° nearer to the equator than the visual auroral zone. The hydrogen zones in the northern and southern hemisphere are apparently conjugate in the eccentric dipole field. The average position of the zone does not vary over a solar cycle; however, at least the equatorward side of the zone expands to lower latitudes with increasing magnetic activity. The intensity of the hydrogen emission falls appreciably as the sunspot minimum is approached. At high latitudes (10–15° from the pole of the eccentric dipole), the occurrence of hydrogen emission was found to be more closely associated with local magnetic activity than with planetary magnetic activity. It seems that much of the magnetic dependence of hydrogen emission occurrence can be explained by motion and/or expansion of the zone with increasing magnetic activity.

IV. Acknowledgments

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