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# A Search for Helium Emissions in the Auroral Zone

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ABSTRACT

A photometric scanning with a sensitivity of 1R failed to detect any λ5876 HeI emission in the auroral zone. An emission feature in this region was found to be part of the 8-2 hydroxyl system. Upper limits of 0.02 to 0.003 are placed on the λ5876/Hβ ratio and the corresponding α-particle/proton ratios are calculated as functions of particle energy.

## 1. INTRODUCTION

Eather[1] has recently estimated the λ5876 HeI emission that would be expected to result from α-particle bombardment of the auroral atmosphere, and has suggested that the emission should be detectable if the ratio $F_\alpha/F_p$ of α-particles to protons is of the order of 0.1. It is evident that if helium emission could be detected, then a delineation of the relative locations of the electron, proton and α-particle precipitation zones would be important additional data that must be consistent with any theory relating to the source and acceleration of auroral particles. Consequently an attempt has been made to detect this emission from Ft. Churchill, Canada (L = 8.6) during the winter 1966-67.

There are two possible sources of contamination that may give rise to distinct emission features in the spectral region of interest: (a) weak, aurorally-associated band emissions, which should be identifiable by enhancement in visual auroras, and (b) weak night-sky emissions (in particular the (8-2) hydroxyl system) which should show a strong van Rhijn effect at all times, and not exhibit any zone of emission as might be expected of the helium emission. To unambiguously identify a feature near 5876Å as helium emission, we considered it necessary to detect a Doppler shift between the magnetic-horizon spectral profiles (as is the case for the hydrogen emission from precipitating protons).

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## 2. EXPERIMENTAL EXPERIMENTS

A tilting-filter photometer [Eather and Jacka[2]] was used to scan the spectral region of interest. The detector was an EMI 6094S photomultiplier kept at -20°C. The interference filter was 2" in diameter and had a peak transmission of 39% at 5880Å, and a half-transmission bandwidth of 2.7Å; filter temperature was controlled at 15°C. Tilting the filter from 0° to 10° scanned the spectral range 5880Å to 5856Å, and a spectral scan was made every 15 seconds. The field of view of the photometer (2.5° half-angle) and changing filter characteristics with angle of incidence result in an increasing effective bandwidth with tilt-angle, but at the same time the percentage transmission decreases, so that the total integrated transmission remains constant to within 10%.

This system allows intensities of about 0 .05 R to be detected in the presence of a night-sky continuum of many times this value, provided the continuum does not undergo appreciable fluctuations in times less than the scan period. The photometer was calibrated absolutely with a $C^{14}$ radioactive light source which was subsequently calibrated against a National Bureau of Standards standard lamp.

The helium photometer comprised one channel of a four-channel photometer that simultaneously measured Hβ (with a tilting filter) and λ3914 $N_2^+$ (fixed filter). Various other filters were used in the 4th channel.

Some typical measurements are shown in fig. 1. Record A shows the trace obtained for the λ5876 line from a He spectral lamp. The next two traces are auroral-zone measurements with the He filter (B) and Hβ filter (C), with the photometer pointed in the magnetic-zenith direction. The lower two traces are He (D) and Hβ (E) measurements near the magnetic-horizon direction. Comparison of (C) and (E) clearly shows the Doppler shift of the magnetic-zenith emission of Hβ. The helium records (B) and (D) are much noisier, and although it is quite evident that there is an emission feature located a few Å to the blue side of the λ5876 position, it is not possible to decide if there is a Doppler shift in the magnetic-zenith direction.

To test the hypothesis that this emission feature may be part of a weak, aurorally-associated band system, a 5862Å tilting filter was used in the 4th channel of the photometer to scan the weak IPG $(8,4)N_2$ line at 5959Å. When there was no visual aurora in the field of view, there was no detectable λ5959 emission, but the emission near λ5876 was always present. When visual auroras were present, λ5959 IPG $(8,4)N_2$ was readily detectable but there was no enhancement of the emission near λ5876. It was thus concluded that the emission is not part of any weak, aurorally-associated band system.

A strong van Rhijn effect was always evident for this emission, with a ratio of about 2.5 for the measured intensity at a zenith angle of $75^{\circ}$ to that in the zenith. This suggests the emission may be an airglow feature, possibly part of the $R_1$ and $R_2$ systems of the (8-2) OH emission that are located in this region [Chamberlain,[3]]. Alternatively, the zone of α-particle precipitation may be very broad, so as to give a van Rhijn effect across the sky at all times.

The final definitive test should be the search for a Doppler shift between the magnetic-zenith and magnetic-horizon profiles, though it is apparent that typical records [fig. 1(B) and 1(D)] are too noisy for this measurement to be made accurately. Consequently spectral scans were summed on a Northern Scientific digital-memory oscilloscope for about 15 minutes (60 scans) and the resultant integrated profiles read out onto a chart recorder. Fig. 2 shows a typical comparison of integrated profiles in the magnetic-zenith and magnetic-horizon directions, as compared with the He spectral lamp. (These profiles have not been corrected for changing filter characteristics with tilt-angle.) It is quite evident that there is little difference between the two profiles and no Doppler shift was observed. About 20 pairs of integrated profiles, obtained at various local times and over many different nights, were compared and there was never any meaningful difference between them. The small differences seen in fig. 2 were completely random. The total integrated intensity (corrected to the zenith) was typically 4-6 R, though on some occasions was less than 2 R.

There seems to be little doubt that the emission detected was part of the $R_1$ and $R_2$ (8-2) OH system. This conclusion was confirmed by measurements at mid-latitudes (Houston, Texas) in May, 1967. Again an emission feature at about 5874Å was detected, and the integrated intensity was 3-4 R. The $R_1(5)$ (5874.2Å), $R_2(1)$ (5873.5Å) and $R_2(5)$ (5874.3Å) lines are probably the main contributors. The average wavelength measured (5873Å ± 0.5Å) would depend on filter characteristics and relative intensities of the contributing lines.

The integrated intensity for the example in fig. 2 is 4.7 R. It is estimated that if there were a helium component present that exhibited a Doppler shift in the magnetic-zenith direction, then an emission of about 1 R would suffice to give a systematic difference in the integrated zenith and horizon profiles. At the same time the Hβ emission at the maximum of the hydrogen arc was 60 R, so an upper limit for the λ5876 He/Hβ ratio is about 0.02 for this example. Higher upper limits were obtained on nights with less hydrogen emission, and in directions away from the hydrogen aurora. The lowest value of this ratio was obtained on the night of February 15-16, 1967 when there was very strong Hβ emission (350 R corrected to the zenith). During this event it was estimated that λ5876 He/Hβ<.003. This event will be discussed separately in section 4.

To try to circumvent the problem of hydroxyl contamination, a 2.5Å tilting filter centered on 4474Å was used on a few nights to search for the λ4471 He line. The expected intensity of this line is only 1/4 that of λ5876 [Head and Hughes,[4]] but the night-sky background in this region is much reduced and there is no hydroxyl problem. No emission was detected between 4474 and 4450Å except in strong visual aurora, when a weak line at 4467Å was recorded. This was believed to be the $N_2^+$ 1N(6-8) line.

## 3. INTERPRETATION

Eather[1] stated that if α-particles and protons enter the atmosphere with about the same velocity distribution (α-particle energy four times the proton energy) then the He λ5876/Hβ ratio should be about two (for the same initial fluxes) throughout the energy range of auroral particles. This statement is incorrect and in fact a ratio of two would

only apply for initial energies above some 150 keV. Eather's[1,5] photon emission curves as a function of energy were replotted against particle range, and the total emission for various initial energies calculated. Listed in Table 1 are the ratios of the total emission of Hβ and λ5876 at various energies to the total emission for fast (≥300 keV) particles, denoted $I_E/I_{300}$. It may be seen that the predicted λ5876/Hβ ratio falls rapidly at lower energies.

Thus the failure to detect helium emission in the auroral zone may be because the total flux of α-particles is too low, or because their average energy is too low, or both. The λ5876/Hβ upper limit of 0.02 obtained above may be used to set upper limits to the ratio $F_\alpha/F_p$ of α-particles to protons, and this upper limit will of course be a function of energy. Upper limits so calculated [assuming a λ5876/Hβ ratio of two at 300 keV particle energy-Eather[1]] are shown in fig. 3 for possible average energies.

Precipitating α-particles have yet to be detected in the auroral zone, so there is no information on average α-particle energies. If 15 keV is taken as a reasonable average energy for auroral protons, then (a) if α-particles have about the same average energy, $F_\alpha/F_p$ must be less than about 6% (b) if the α-particle energy is about twice the proton energy [as suggested by Speiser[7]] then $F_\alpha/F_p$ must be less than about 2% (c) if α-particles and protons have about the same velocity, the $F_\alpha/F_p$ must be less than about 0.7%. It might be noted that recent observations of solar-wind ions [Hundhausen et al.[6]]gave an α-particle/proton ratio in the solar wind varying from 0% to 15%, with a mean value of 4% for the period of observation. Solar-wind observations from the Pioneer 7 and Vela satellites on the particular days during which these photometric measurements were made gave ratios of 1-4% (Wolfe, private communication; Bame, private communication). Little can be said regarding comparison of solar wind and auroral ratios, even if the solar is the source of auroral protons and α-particles, as the details of the intermediate extraction and acceleration processes are unknown. A cautionary note should be added: both the expected Hβ and He emission (from fast protons and α-particle interations with the atmosphere) were calculated from rather

uncertain experimental and theoretical cross-section data [Eather[1,5]]. These uncertainties are probably no more than a factor of two, but it should be kept in mind that similar uncertainties apply to the $F_\alpha/F_p$ ratios quoted above.

It is concluded that, after making reasonable assumptions regarding α-particle and proton energies, the optical observations do not preclude ratios $F_\alpha/F_p$ from 1-10%.

## 4. THE EVENT OF FEBRUARY 15-16, 1967

Unusually strong hydrogen emission was observed on the night of February 15-16, 1967, the maximum intensity recorded was 350 R (corrected to the zenith). This event was apparently associated with a very strong solar flare that was reported about 1800 U.T. on February 13th. There was no PCA event accompanying the flare (Reid, private communication), and the diurnal movements of the hydrogen emission zone during the night (fig. 4) followed the typical auroral-zone morphology (equatorward movement before midnight and return to higher latitudes in the morning hours). It is thus considered that this was a strong, auroral hydrogen arc, rather than a PCA emission.

Only normal Hβ intensities (maxima of 50-70 R at Churchill) were recorded on the night of February 14-15, while intensities were lower than normal on the night of February 16-17. Assuming the enhanced proton flux was solar in origin, a lower limit may be placed on the solar-wind proton energy at this time; 55 hours elapsed between the solar flare and the first measurement of enhanced hydrogen emission. This gives a lower limit for the velocity of protons in the solar wind of 750 km/sec, which is not unreasonable for periods of strong activity [Snyder et al[8]]. The $\Sigma K_p$ index reached $39^+$ on February 16th.

Again no λ5876 HeI emission was detected in this display, and it was estimated that the ratio of λ5876/Hβ was ≤0.03%. If there were precipitating α-particles with typical auroral energies (10-30 keV say), then a consideration of fig. 3 places upper limits on $F_\alpha/F_p$ between 0.2% (proton energy 30 keV, α energy 10 keV) and 5% (proton energy 10 keV, α energy 30 keV).

During this period of strong solar activity, $F_\alpha/F_p$ ratios measured in the solar wind by the Vela satellite were unusually high, varying between 5 and 15% (Bame, private communication). It is concluded that the auroral acceleration process must either preferentially accelerate protons to higher energies than α-particles, or guide the α-particles to a different region (perhaps to lower latitudes that are not observable from Churchill). It is hoped that similar measurements might be attempted at lower latitudes in the near future.

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## CAPTIONS FOR FIGURES

Fig. 1 Typical measurements with the tilting-filter photometer of auroral Hβ and the spectral region near λ5876Å. The marker pen trace at the very top indicates when the filter is at $0^{\circ}$, and between each such mark, the filter tilts from $0^{\circ}$ to $10^{\circ}$ and back again, and so completes two spectral scans.

A. Helium lamp source.
B. Scan from λ5880-5856Å in the magnetic zenith direction.
C. Scan of Hβ in the magnetic-zenith direction.
D. Scan from 5880-5856Å in the magnetic horizon direction.
E. Scan of Hβ in the magnetic horizon direction.

See text for further explanation.

Fig. 2 Integrated spectral sums over 60 wavelength scans in the 5880-5856Å region, compared with a He spectral lamp. The magnetic-horizon scan has been normalized to the same peak intensity as the magnetic-zenith profile.

Fig. 3 Upper limit for the ratio of α-particles/protons precipitating into the auroral atmosphere.

Fig. 4 Diurnal movement of the region of hydrogen emission on the night February 15-16, 1967 at Ft. Churchill, Canada.

TABLE 1

Energy dependence of Hβ and λ5876 He I emission

| Energy E (keV) | $\frac{I_E}{I_{300}}$ (Hβ) | $\frac{I_E}{I_{300}}$ (λ5876 He I) |
|---|---|---|
| 300 | 1.00 | 1.00 |
| 200 | 0.97 | 0.95 |
| 100 | 0.70 | 0.51 |
| 30 | 0.32 | 0.10 |
| 10 | 0.14 | ~0.01 |

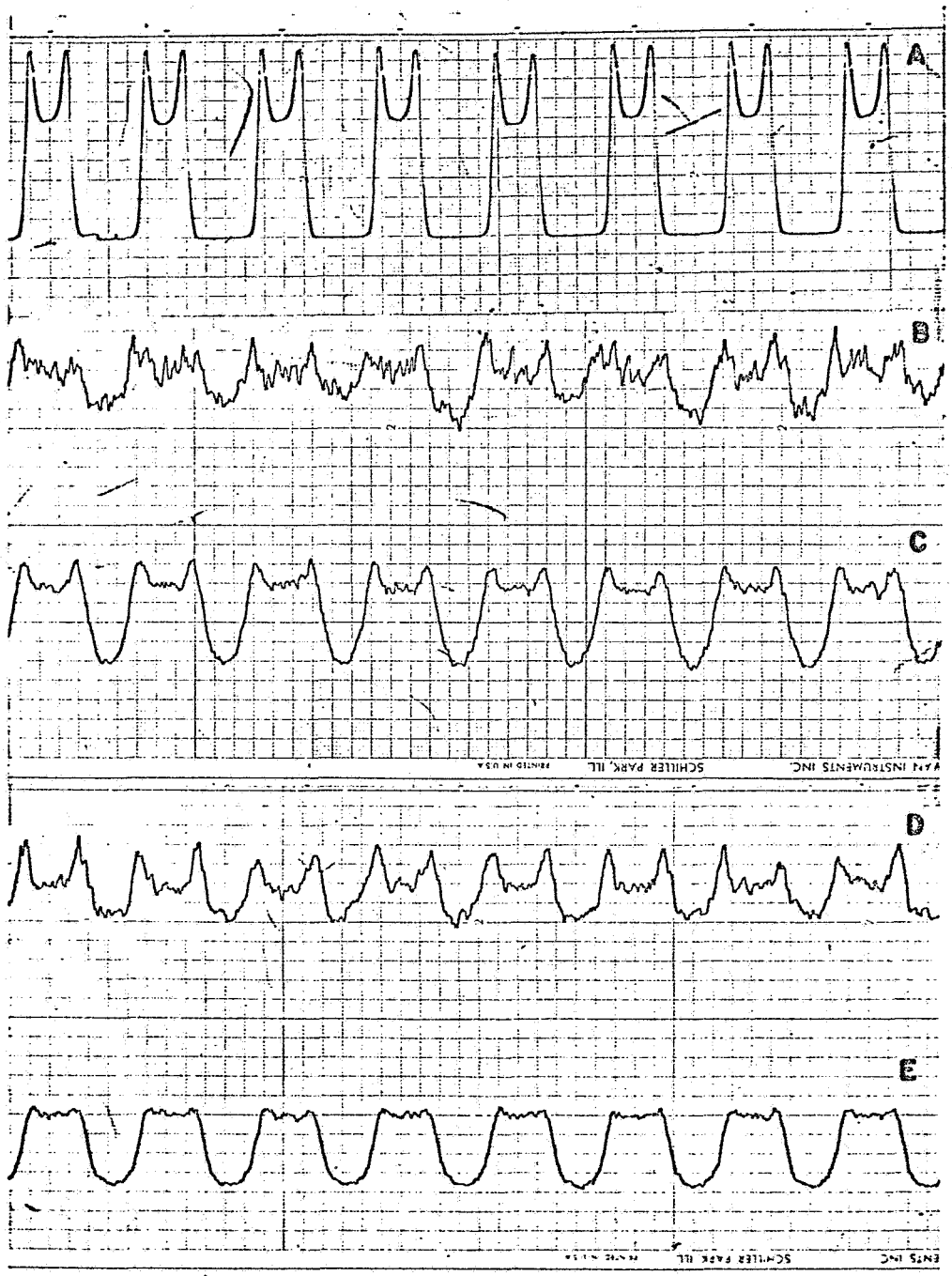


Fig. 1

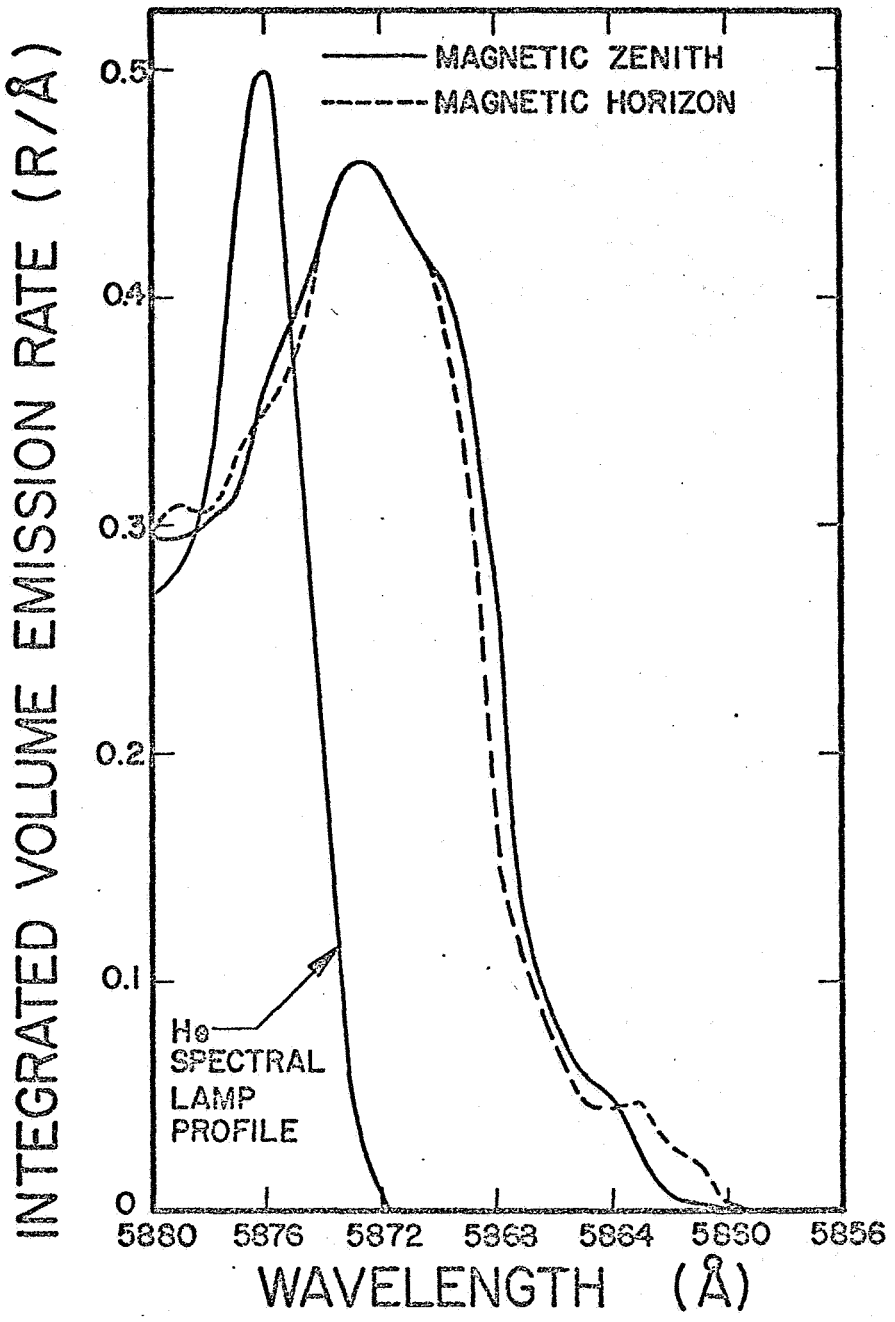
MAGNETIC ZENITH
MAGNETIC HORIZON
INTEGRATED VOLUME EMISSION RATE (R/Å)
0.5
0.4
0.3
0.2
0.1
0
He SPECTRAL LAMP PROFILE
5880
5876
5872
5868
5864
5860
5856
WAVELENGTH (Å)

Fig. 2

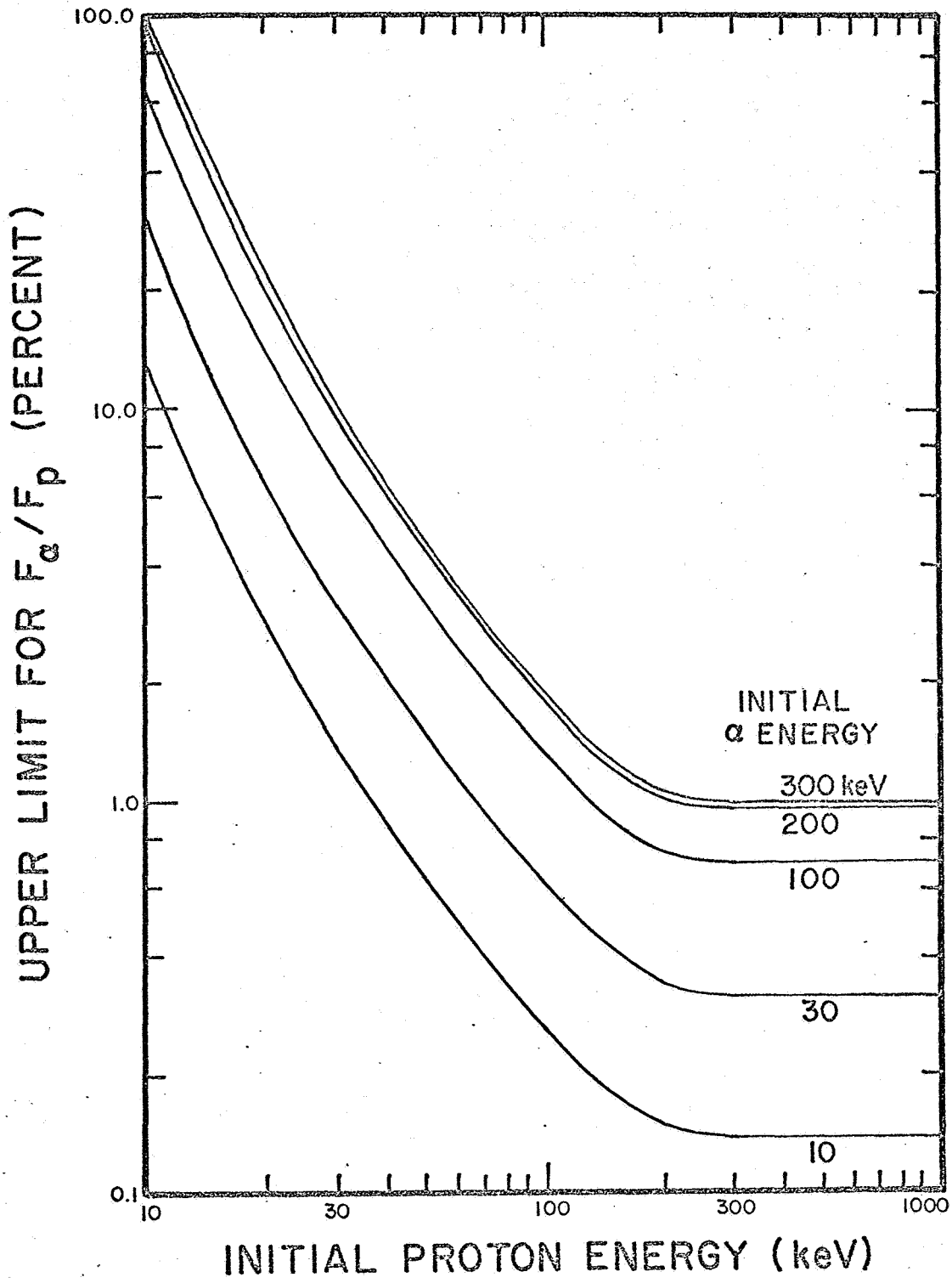
100.0
10.0
1.0
0.1
UPPER LIMIT FOR $F_\alpha / F_p$ (PERCENT)
INITIAL
α ENERGY
300 keV
200
100
30
10
10
30
100
300
1000
INITIAL PROTON ENERGY (keV)

Fig. 3

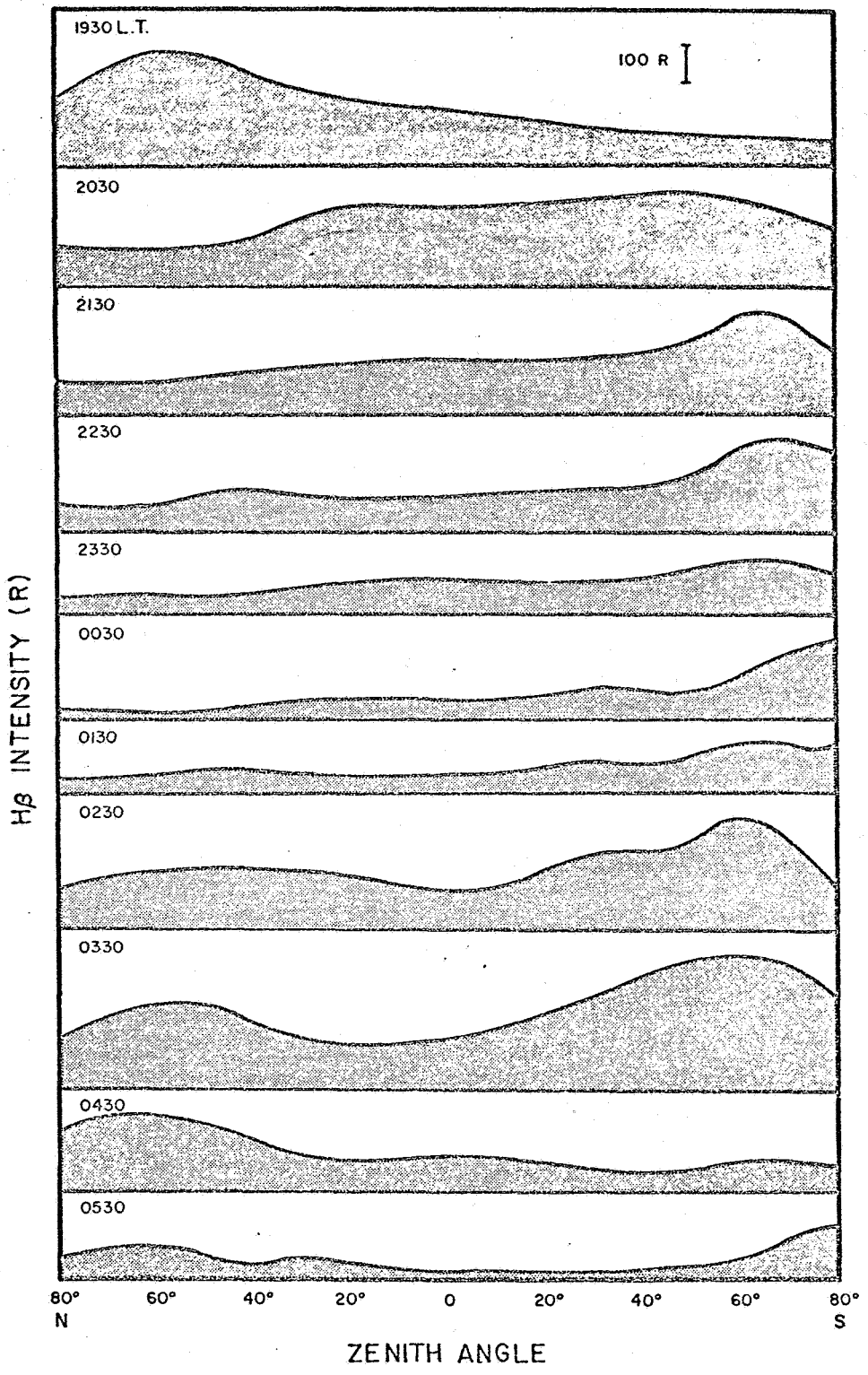
1930 L.T.
100 R
2030
2130
2230
2330
0030
0130
0230
0330
0430
0530
Hβ INTENSITY (R)
80° N
60°
40°
20°
0
20°
40°
60°
80° S
ZENITH ANGLE

Fig. 4