Hydrogen Emission in Pulsating Auroras*

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ABSTRACT

Simultaneous measurements of electron-excited emissions and $H\beta$ emission during three pulsating auroras (5-15 second period) showed no detectable $H\beta$ pulsations. An upper limit for any $H\beta$ modulation is about 1/8 the percentage modulation of the electron-excited emission. If this result is true in general, it limits possible pulsation mechanisms to those involving plasma instabilities. A single observation of a pulsating aurora with a 50-200 second period is also reported; both $H\beta$ and electron-excited $\lambda 5577$ OI were modulated to the same extent. It is believed a different mechanism was responsible, possibly loss-cone modulation by hydromagnetic waves near the equatorial plane.

1. INTRODUCTION

It has been known for some time that "quiet-form" auroras often fluctuate or pulsate in brightness. The pulsations are quasi-periodic, and pulse durations and separations range from about 0.05 seconds to tens of seconds, and sometimes minutes. The pulsations usually consists of only a 1-20% modulation of the total brightness (typically less than 3 kR for these quiet-form auroras) and rarely exceeds 50% of the total brightness. There seems to be an occurrence maxima of pulsating auroras along the lower-latitude side of the auroral zone, and they usually occur in the morning hours after auroral breakup.

Pulsations in approximately the same frequency range have been observed in the geomagnetic field and are a regular feature of auroral x-rays. Various degrees of correspondence have been reported between geomagnetic micorpulsations, auroral x-ray pulsations and light pulsations. For a review of the main characteristics of pulsating auroral events, together with appropriate references, the reader is referred to a recent article by Shepherd (1967).

The cause of auroral pulsations is not known, and these pulsations may represent fluctuations in the particle source, in magnetospheric conditions along the particle path, or in ionospheric conditions at the particle "sink". It should be emphasized that we are discussing pulsations in quiet-form auroras (typically diffuse arcs or patches with green line intensities of perhaps a few kilo rayleighs) as distinct from bright, active forms where rapid appearances and disappearances of rays may give rise to the pulsations with frequencies of 10-20 cycles/sec^{-1} (Paulson and Shepherd, 1966a).

The only direct (rocket) measurements of relevance (Evans, 1967, Mozer, 1967; Winiecki et. al., 1967) have detected pulsating electron fluxes in the 10-20 cycle sec^{-1} frequency range. On the other hand, rockets are rarely fired into the weak, diffuse type of auroral arc or patch in which the quiet-form pulsations occur.

It is clear that a study of the behavior of auroral hydrogen emission during these pulsation events should give important additional information that must be compatible with any theory that attempts to explain pulsations. The best way to attack the problem would be to measure simultaneously the light (possibly, though not necessarily, excited mainly by low-energy electrons), x-rays (generated by higher-energy electrons) and hydrogen emission (excited by protons); though rocket measurements of proton and electron fluxes over a wide energy and pitch-angle range during pulsation events would perhaps be a more definitive experiment. Section 2 of this paper will critically review previous measurements interpreted as pulsating Hβ emission, and show the pulsations observed at the wavelength of Hβ could have been due to auroral contamination. Section 3 will present new measurements showing no measureable fluctuations in the Hβ emission in pulsating auroras recorded in the 5-15 sec period range. This result allows the rejection of a number of suggested modulation mechanisms. In Section 4 it is concluded that the only mechanisms that are not at variance with the experimental data are those involving instabilities.

2. Previous Measurements

The first measurements at Hβ wavelength during auroral pulsations were reported by Dzhordzhio (1962) and he found good correlation between λ3914 N_2^+ pulsations and pulsations at the wavelength of Hβ (periods ~10 secs). However, Dzhordzhio used a 100Å filter to try to isolate Hβ, and he concludes that Hβ only formed a small part of the total signal through the filter, the main contribution being night-sky background and "auroral continuum". The auroral continuum referred to presumably comprises weak band systems in the region, probably the Vegard-Kaplan N_2 system. (Note however that the Vegard Kaplan system has a life-time of about 10 seconds, which should lead to a smoothing out and attenuation increasing at higher pulsation frequencies.) Dzhordzhio clearly states that the good correlation he observed between λ3914 N_2^+ and a 100Å band centered on Hβ was a relationship between λ3914 N_2^+ and this auroral continuum; he does not claim a correlation with Hβ.

The only other attempt to measure Hβ pulsations has been by Paulson and Shepherd (1966b), and they reported an excellent correspondence between λ3914 N_2^+ and Hβ when the latter was detected. Paulson and Shepherd felt that they were indeed measuring Hβ radiation, but conceded that contamination from some other highly variable feature of the auroral spectrum could be the cause of their 4861Å signal. [They noted that there was some suggestion of a time lag between the 3914 N_2^+ emission and the Hβ signal. This would be consistent with contamination from the Vegard-Kaplan bands, as they have a lifetime of some 10 seconds. (Any time lag would be a function of this lifetime and of the shape of the excitation function.)]

Eather (1967a) has investigated the problem of contamination of Hβ measurements by recording the contamination from visual aurora at three separate wavelengths (Hβ-20Å, Hβ, Hβ + 20Å) using 10Å bandwidth filters. The contamination was roughly the same in all channels. The possibility of finite transmission at other auroral wavelengths was checked by placing two filters centered on Hβ (bandwidths 2.0Å and 40Å) in series; the contamination was about the same as before. (Filter transmission outside the passband is normally < 0.01%, so two filters in series should reduce any transmission outside the passband by a factor of $\sim 10^4$) Eather concluded that some unresolved auroral feature near Hβ, probably the Vegard Kaplan (2-15) system, was responsible for the contamination. He states the contamination associated with 1 kR of λ3914 N_2^+ emission is about 0.2 R/Å, (resulting in an apparent increase in Hβ of about 8 R if a 40Å filter is being used to isolate Hβ) and stresses the point that simultaneous background measurements must be made to obtain meaningful Hβ results.

Examination of an example of simultaneous λ3914 N_2^+, λ5577 OI and Hβ pulsations published by Paulson and Shepherd (1966b--their Figure 13) shows that the Hβ modulation observed was about 12% of the total signal. There are no absolute calibrations on the published example, but it is stated elsewhere in the paper that typical modulation amplitudes at λ5577 were 1 kR. If we assume an associated λ3914 N_2^+ modulation of 0.5-1 kR, the expected contamination according to Eather (1967a) would be about 4-8 R. If this is 12% of the total signal, this total would be about 35-70 R.

Possibly 15 R of this can be attributed to night sky continuum (0.35 R/Å in this region, Eather (1967b)). The remaining 20-55 R is certainly not unreasonable for auroral Hβ intensities, which typically average 40-100 R near the maximum of hydrogen arcs (Eather, 1967b). It is thus possible that Paulson and Shepherd may have been measuring contamination rather than Hβ pulsations.

3. Experimental

The tilting-filter photometer described in the preceding paper (Eather, 1967c) was used to make these measurements. The Hβ filter used had a peak transmission of 52% at 4864Å, and a half-transmission bandwidth of 2.0Å. All measurements to be reported in this paper were corrected for atmospheric extinction and scattering, and for the van Rhijn effect, as outlined by Eather (1967b).

Only four examples of pulsating aurora were detected during about three weeks of observations at Fort Churchill, Manitoba (L = 8.6) in November 1966, February and March 1967. Such low incidence of pulsating auroras at these high latitudes was not unexpected; the measurements were made from Churchill simply because the equipment was located there for support of various rocket experiments.

(a) 15 November 1966. This event occurred near 0200 L.T. and was located south of Churchill (the measurements were made at an elevation angle of 40° to the south). A meridinal scan just before the event (Figure 1) shows the locations of the hydrogen emission zone, and subvisual auroral arcs that were present at the time. Simultaneous Hβ, λ4709 N_2^+ and λ5577 OI measurements are shown in Figure 2. Mean λ4709 N_2^+ and λ5577 OI intensities were 35 R and 730 R respectively, while the Hβ intensity was 15 R. The Hβ intensity is proportional to the modulation of the Hβ record (see <u>Eather and Jacka</u>, 1966; <u>Eather</u>, 1967c) and so only one measurement of the Hβ intensity is obtained every 15 seconds. It may be seen from Figure 2 that the background measurement near Hβ (the bottom of the Hβ modulation record) is constant throughout the event; the record itself is rather noisy, and estimates of the modulation depth at each peak have been marked between the Hβ and λ4709 N_2^+ records. It may be seen that the the Hβ intensity certainly does not follow the pulsations in λ5577 OI and λ4709 N_2^+.

Let us consider the absolute intensities involved more closely. <u>Eather</u> (1967b) has measured the ratios λ5577 OI/Hβ and λ4709 N_2^+/Hβ in what he considers to be pure proton auroras. Using these results, we calculate a λ5577 OI intensity of 360-565 R for the sum of the airglow continuum, and proton excited contributions. This implies that the remaining 165-270 R of the measured λ5577 OI signal was electron excited. Now the modulation amplitude varies from about 100-300 R during the event, and averages around 200 R; it thus appears that the pulsating λ5577 OI signals is excited entirely by electrons, and that the modulation of the electron flux in the larger pulsations approaches 100%. We can check this hypothesis by considering the λ4709 N_2^+ signal: <u>Eather's</u> (1967b) measurements show that the ratio λ4709/Hβ in proton auroras is about 1.0, and so predict a proton-excited component of the λ4709 N_2^+ emission of 15 R for this event. The night sky background in this region is about 0.35 R/Å (<u>Eather</u>, 1967b) and so will give a total background through the 38Å filter used of about 13 R. This leaves 8 R of λ4709 N_2^+ emission that is attributed to electron excitation. The expected 3914 N_2^+ intensity would be then about 140 R i.e. a λ3914 N_2^+/λ5577 OI ratio for electron excitation of 0.5-0.8, which seems quite reasonable (<u>Stolarski and Green</u>, 1967).

We conclude that this pulsation event was excited entirely by a modulated electron flux, and that this modulation at times approached 100%. The resultant light emissions were superimposed upon unmodulated, proton-excited emissions and the normal night-sky and airglow background. (We note the expected contamination from the electron-excited Vegard-Kaplan bands near Hβ would be about .03R/Å (Eather, 1967a). This should have given a 3% modulation of the Hβ signal, which would have been difficult to detect because of the noisy Hβ record.)

From the analysis of this event, and considering the probable errors (because of the signal noise) in measurement of Hβ intensity, it appears that ~ 100% modulation in the electron flux was accompanied by no more than about a 10% modulation of the proton flux.

(b) 17 February 1967: This event occurred near 0300 L.T. and the pulsating region was located south of Churchill at a elevation of 15°. Simultaneous Hβ and λ3914 N_2^+ intensities were 13 R and 1520 respectively. The expected λ3914 N_2^+ intensity excited by the protons that produce the 13 R of Hβ is only about 220 R, while the total night-sky background transmitted by the λ3914 filter would not exceed 20 R. It is evident then that the larger part of the λ3914 N_2^+ signal (about 1280 R) must have been electron excited. From 0249 LT to 0252 LT, the 2.0Å bandwidth Hβ filter was tilting and so scanned the Hβ wavelength region; from 0252 LT to 0256 LT the filter was stopped on the peak of the profile. It is evident from this latter interval that pulsations in the λ3914 N_2^+ intensity were accompanied by corresponding pulsations in the signal transmitted by the 2.0Å Hβ filter centered at 4861Å, though the magnitude of the pulsations (less than 10% of the Hβ signal) was considerably less than the percentage fluctuations in the electron excited λ3914 N_2^+ (~ 40% for the larger pulsations). The section of record from 0256 to 0258.30 L.T. has been amplified by a factor of five (and zero offset), while the section 0258.30 to 0301 L.T.

has been amplified by a factor of two (and zero offset); although the Hβ record in each case is rather noisy, it is evident that fluctuations in λ3914 N_2^+ are followed by the Hβ signal, but with decreased percentage amplitude. The rest of the record extending up until about 0310 L.T. shows a similar behavior.

The important question is: do these fluctuations at 4861Å represent genuine auroral Hβ fluctuations, or are they a result of contamination? The record between 0251 and 0252 LT provides an important clue, at 0251.20, a fairly large λ3914 N_2^+ pulsation is followed by the Hβ channel, and at this time the tilting filter was centered near the peak of the profile; at 0251.35 a similar λ3914 N_2^+ pulsation is again clearly followed by the Hβ channel, but at this time the tilting filter was centered at the edge of the profile, and so was essentially measuring the background. (Note that these measurements at an elevation angle of 15° are essentially of the magnetic-horizon Hβ profile, and so the scanning range 4864-4840Å is sufficient to scan the complete low-wavelength side of the profile.)

It is concluded that indeed the recorded pulsations at the Hβ wavelength were background fluctuations. This may be confirmed by calculating the expected contamination using (<u>Eather's</u> (1967a,b) results; the amplitude of the larger λ3914 N_2^+ pulsations near the beginning of Figure 3 is about 500 R. The expected contamination is about .1 R/Å which compares with the measured modulation amplitude at Hβ of 0.12 R/Å.

c) <u>11th March, 1967</u>: This event occurred near 0315 L.T.and the pulsating region was located south of Churchill at an elevation of 15°. Simultaneous measurements of λ3914 N_2^+ , 4881A, (10Å filter), 4861Å (10Å filter) and 4864 (2.0 A filter) are shown in Figure 4 (note that the Hβ filters were not tilting, except for one cycle at 0320 L.T.; the 4881Å filter scanned down through the auroral Hβ peak, and then slightly to the low-wavelength side of the profile; the two filters centered near Hβ scanned down the low-wavelength side of the profile.) Average Hβ and λ3914 N_2^+ intensities were 12 R and 640 kR respectively. The expected proton excited λ3914 N_2^+ is only 200 R, so again most of the λ3914 N_2^+ (~420 R) must have been electron excited. Close examination of the records shows that λ3914 N_2^+ pulsations are followed by both Hβ channels and also by the Hβ + 20Å channel, but with decreased percentage modulation. This example, together with the previous example, clearly demonstrates that there is an aurorally-associated contamination right through the 4840-4880Å region. As mentioned before, the contamination is probably weak, unresolved Vegard-Kaplan bands.

Consider the larger λ3914 N_2^+ at 0315 U.T.; the modulation magnitude is 125 R (~30% of electron excited signal) and the expected contamination (Eather, 1967a,b) is about .025 R/Å, which compares with the measured value of about .030 R/Å (from 2.0Å filter measurements), about .04 R/Å (from 10Å filter measurement) and about .045 R/Å (from 4881 filter measurement). These varying measured values probably indicate the contamination is non-uniform with wavelength, though the records are too noisy to permit any detailed investigation.

It is concluded from the three examples discussed above that there is very little (if any) modulation of the hydrogen emission during pulsating auroras. An upper limit for the percentage modulation is about 1/8 the percentage modulation of electron-excited N_2^+ and OI emissions.

d) <u>13 November 1966</u>: This pulsation event had completely different characteristics to those discussed above. It occurred north of Churchill early in the evening (1820-1900 L.T.) and the period of the pulsations was of the order of 1-3 minutes. Mean Hβ and λ5577 OI intensities were about 38 R and 2.4 kR respectively. The sum of the airglow and proton-excited components of the λ5577 OI intensity should be about 500 R, implying that the remaining 1.85 kR was electron-excited. Because of the long pulsation periods, the 2.0Å tilting filter was adequate for measuring the Hβ changes, and Figure 5 shows a plot of the Hβ and λ5577 OI intensities during the event.

Pulsations in the λ5577 OI intensity are accompanied by almost identical pulsations in the Hβ intensity, and the percentage modulation is similar for both emissions. We conclude that both the proton and electron fluxes were being modulated to the same extent during this event.

In view of the completely different time of occurrence, position of occurrence, and pulsations frequency for this event compared to the others discussed above, there was probably a different mechanism involved, and so this event is not regarded as contradicting our previous conclusion that hydrogen emission does not pulsate in normal pulsating auroras; that is, the type that occur towards lower latitudes in the morning hours, and have pulsation periods of the order of 10 seconds.

These results should be regarded as preliminary, especially as only four events have been studied. It is planned to carry out further measurements from a lower-latitude auroral station this winter.

4. Some Suggested Mechanisms

The preceding section has illustrated an important characteristic of pulsating auroras in the 5-15 sec period range: when there is simultaneous proton and electron precipitation, pulsations are confined to the electron flux and there are no pulsations (or at least very greatly reduced pulsations) in the proton flux. Also, there have been considerable photometric studies of the hydrogen emission in the last 10 years (see review by Eather, 1967a) and fact variations in the hydrogen intensity have never been reported. Similarly, rocket measurements have not shown any rapid variations in proton flux, though rapid electron flux variations are common (Mozer, 1967). We thus feel there is sound basis for making the generalization that the proton flux in pulsating auroras throughout the .05-20 second period range is rarely, if ever, modulated appreciably.

This section will briefly review suggested mechanisms for pulsating auroras in light of this new information.

a) Mirroring hypothesis: Mirroring of charged particle bunches in the geomagnetic field has been considered as a possible explanation of pulsating auroras but has been rejected on a number of grounds (Paulson, 1963; Johnanson and Omholt, 1966; Paulson and Shepherd, 1966). First, the large and random variations in time between successive pulses does not support the theory; the mechanism also requires almost monoenergetic electrons, and a process that scatters an almost constant number of trapped electrons into the loss cone at the appropriate time during each pass between mirror points; also, typical mirroring periods for electrons with auroral energies are too short to explain the longer-period pulsations, and too long to explain the high-frequency pulsations; finally studies of drifts of pulsating regions lends no support to the mirroring hypothesis (Paulson and Shepherd, 1966b; Cresswell and Davis, 1966).

If the hydrogen emission did pulsate with typical periods of the order of 10 seconds, the mirroring hypothesis would require almost monoenergetic 2 MeV protons [the mirroring period of a 2 MeV proton at zero pitch angle on the $L = 6$ shell is about 10.6 sec (Hamlin et. al., 1961]. This is a much higher energy than normally attributed to auroral protons. The long pulsation periods associated with the event of 13 November would correspond to more acceptable energies ($\sim$ 10 keV), but the quasi-periodic nature of the pulsations, and correlation with electron produced emission, precludes the mirroring hypothesis as a possible explanation.

(b) Instabilities: (i) Chamberlain (1963) has suggested that a Krall-Rosenbluth plasma instability may be generated in the auroral situation, and could cause auroral pulsations. Chamberlain and Paulson and Shepherd (1966b) point out that such a process is attractive as the pulsation spectra need not represent the mirroring period directly, but only the period of the overall disturbance. One of the conditions for the growth of this instability is that the mean ion energy is much greater than the mean electron energy; this condition is not satisfied by the auroral particles themselves (both proton and electron energy spectra in auroras appear to peak in the 1-10 keV range), but may well be satisfied at some earlier stage in the particles' history, for example in the solar wind, at the magnetospheric boundaries or in the geomagnetic tail. However, for this mechanism to be effective in producing auroral pulsations, it must be located along closed lines of force that connect to the auroral zones [and as the mean ion energy must be much greater than the mean electron energy in this region, it implies that the ejected particles (at least the protons) must be accelerated to auroral energies at low altitudes]. If all these conditions were satisfied and the instability did develop, the theory predicts the electrons will carry the greater current and supply the bulk of the auroral excitation, with a simultaneous weaker ion bombardment in the opposite hemisphere. The present results showing no definite Hβ pulsations in phase with electron-excited pulsations, and no trace of Hβ pulsations out of phase with the electron-excited pulsations, show that the instability is not important in producing a modulation in the precipitating proton flux. It may be a source of electron flux modulation, provided the conditions mentioned above are satisfied.

Another type of instability (actually an overstability) has been suggested by <u>Evans</u> (1967) to explain a 10 Hz modulation he observed in auroral electrons. The dynamics of this overstability have been discussed by <u>Stix</u> (1964) and <u>Evans</u> (1967); a beam of near monoenergetic electrons may excite a wide range of plasma oscillations in the local (within 1000 km of the earth) plasma. Some of these oscillations grow exponentially and accelerate certain electrons ($\omega_c \approx \omega_p$) in the beam; these are the electrons that form the pulsations. Finally the transfer of energy from waves to particles will exceed the growth of the wave, and the disturbance will be damped. The pulsation frequency does not represent the driving wave frequency, but rather the growth and decay time of the disturbance. Such an overstability will not have any measurable affect on protons.

This mechanism appears to be promising, and if it is triggered by different energy beams at different positions near the earth (500-1500 km), it may be able to excite a range of periodicities. As Evans (1967) points out, the questions of what wave modes should be expected in the 500 - 1500 km region and their associated growth and decay rates, need to be investigated.

(c) Proton fluctuations: Hilliard (1964) suggested that the pulsations might be caused by protons, with the background aurora caused by electrons. The present results showing no Hβ pulsations allows this suggestion to be rejected, unless the protons have energies of the order of 1 MeV or more. If this was the case, they could penetrate to 90 km and lower, where collisional-ionization quenching of the H(4s) state could result in λ3914 N_2^+ and λ5577 OI emissions with negligible associated Hβ emission (Bates and Walker, 1966). However, there are further objections to proton-excited pulsations: a correspondence between light pulsations and x-rays has been reported (Rosenberg, et. al., 1967), and protons have an extremely low efficiency for producing x-rays. Finally, no rapid variations in proton fluxes at any energy have been observed by rocket-borne instruments, whereas electron fluctuations are commonly observed.

(d) Atmospheric density fluctuations: This suggestion is readily rejectable as it cannot explain large-amplitude pulsations, or x-ray pulsations.

(e) Ionospheric processes: Spatial structure in the flux of precipitating particles will result in spatial structure in the electron density in the ionosphere. This could result in enhanced ionospheric currents in these regions, the magnetic effects of which will modify the loss cone so as to decrease the precipitation in that area. Calculations using an initial latitudinal-dependent flux with fixed latitude boundaries indicate that pulsations will result (Maehlum, private communication). The effectiveness of this process as a pulsation mechanism increases for pitch-angle distributions peaked near 90°, and the pulsation period decreases with increasing flux. If the mechanism were important, its effect on protons would be difficult to estimate without a knowledge of the proton pitch-angle distribution. For strongly peaked distribution near 90°, the mechanism should be equally effective for protons, and coherent pulsations in the hydrogen emission and electron-excited emissions would be expected. Strongly peaked pitch-angle distributions near 90°, coupled with very high electron fluxes, result in pulsation periods of some 20 seconds (Maehlum, private communication). Thus it does not seem that this mechanism can explain typical weak, pulsating auroras with periods of 5 seconds or so, and certainly cannot account for higher frequency pulsations.

(f) Solar-wind energy density modulation: The geomagnetic effects associated with an energy density modulation of the solar wind (Willis, 1965) might represent a possible mechanism for pulsating auroras. Hydromagnetic waves will be generated, and will modify particle pitch-angle distributions and result in periodic precipitation (Watanabe, 1964; Willis, 1965). The process will proceed most effectively near the equator where low-amplitude hydromagnetic variations will result in the most significant variations.

Typical hydromagnetic wave periods in the magnetosphere (60-1000 seconds) are too long to explain auroral pulsations in the .05 - 15 second range. It is possible that the longer period event of 13 November, 1966 may be attributed to a hydromagnetic modulation mechanism; both protons and electrons should be modulated similarly, and so the hydrogen emission would be expected to pulsate with the electron-excited emissions. If the modulation is fairly well confined to equatorial regions and we assume an electron energy of 10 keV, the time delay of the order of 30 seconds would be expected between electron and proton peaks (for a proton energy of 10 keV), or 10 sec for a proton energy of 100 keV (Hamlin, 1961). The present measurements do not preclude the possibility of time lags of the order of 10-20 sec as Hβ intensities were only obtained at intervals separated by 10 and 20 seconds.

(g) Geomagnetic flux-tube motions: Cladis (1967) has suggested that transient motion of magnetic tubes that are suddenly heated by the injection of high-energy plasma will result in periodic electron precipitation. Calculated periods in the plasma - sphere from L = 2 to about L = 5 are 20 - 250 seconds, but periods as low as a few seconds might be appropriate for the much lower plasma densities in the plasmapause (Carpenter, 1966)(and flux tubes connecting to the auroral zone pass through this low plasma-density region). However, this mechanism cannot explain pulsation periods of fractions of a second; nor have the predicted north-south fluctuations of the pulsation region been observed.

5. Conclusions

None of the mechanisms discussed in section 4 satisfactorily explains the characteristics of pulsating auroras. These characteristics seem to demand separate mechanisms to explain pulsation periods less than about 15 seconds, and those greater than a few tens of seconds. Perhaps the presence or absence of the hydrogen pulsations may distinguish the mechanism involved in the uncertain 10-30 second-period "crossover region."

The only mechanisms suggested to explain the shorter period pulsations that are not at variance with measured characteristics are those involving instabilities in wave-particle interactions. However, this may not be true when the qualitative features of suggested instabilities are derived in the magnetospheric domain. The overstability described by Evans (1967) and Stix (1964) is believed to have been observed in the laboratory (Smullin and Getty, 1962) but laboratory plasmas are collision dominated, and so laboratory phenomena may not simply scale up to the magnetospheric environment.

The longer-period pulsations may be explainable in terms of loss-cone modulation by hydromagnetic waves near the equator, though the source of the hydromagnetic waves has yet to be specified.

Auroral pulsation events may be directly related to an auroral acceleration mechanism, and could manifest the dynamics of the disturbance growth and decay. Consequently, co-ordinated ground (optical and micropulsations), balloon (optical and x-ray) and rocket (particle) measurements during pulsation events may be an extremely valuable undertaking.

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FIGURE CAPTIONS

Fig 1. Meridinal scan showing the locations of the hydrogen emission zone, and subvisual auroral arcs, at the time of the pulsation event of 15 November, 1966.

Fig 2. Hβ, λ4709 N_2^+ and λ5577 OI measurements during a pulsating aurora. See text [section 3(a)] for full discussion.

Fig 3. Hβ and λ3914 N_2^+ measurements during a pulsating aurora. See text [section 3(b)] for full discussion.

Fig 4. Measurements at λ3914 N_2^+ , Hβ and Hβ + 20A during a pulsating aurora. See text [section 3(c)] for full discussion.

Fig 5. Hβ and λ5577 OI measurements during a long-period pulsation event. See text [section 3(d)] for full discussion.

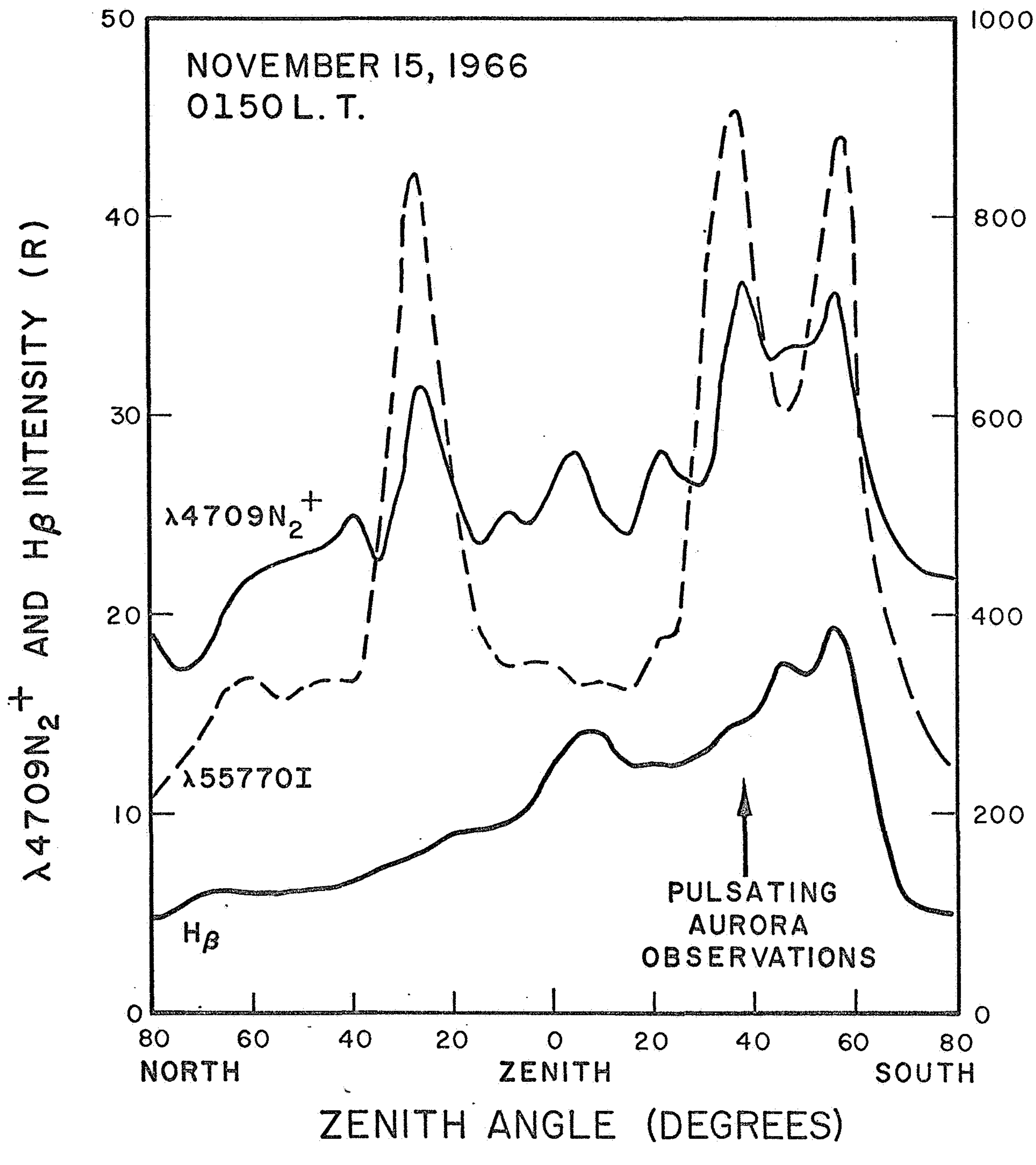

FIGURE 1

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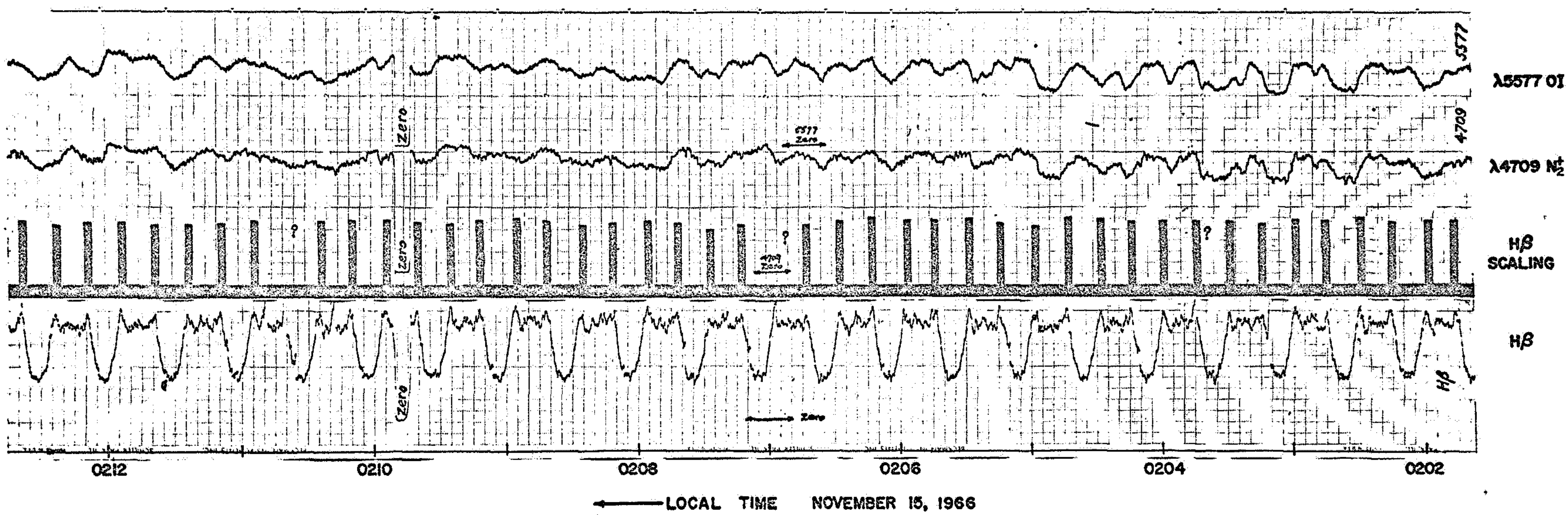
λ5577 OI
λ4709 N_2^+
Hβ SCALING
Hβ
0212
0210
0208
0206
0204
0202
LOCAL TIME NOVEMBER 15, 1966

FIGURE 2

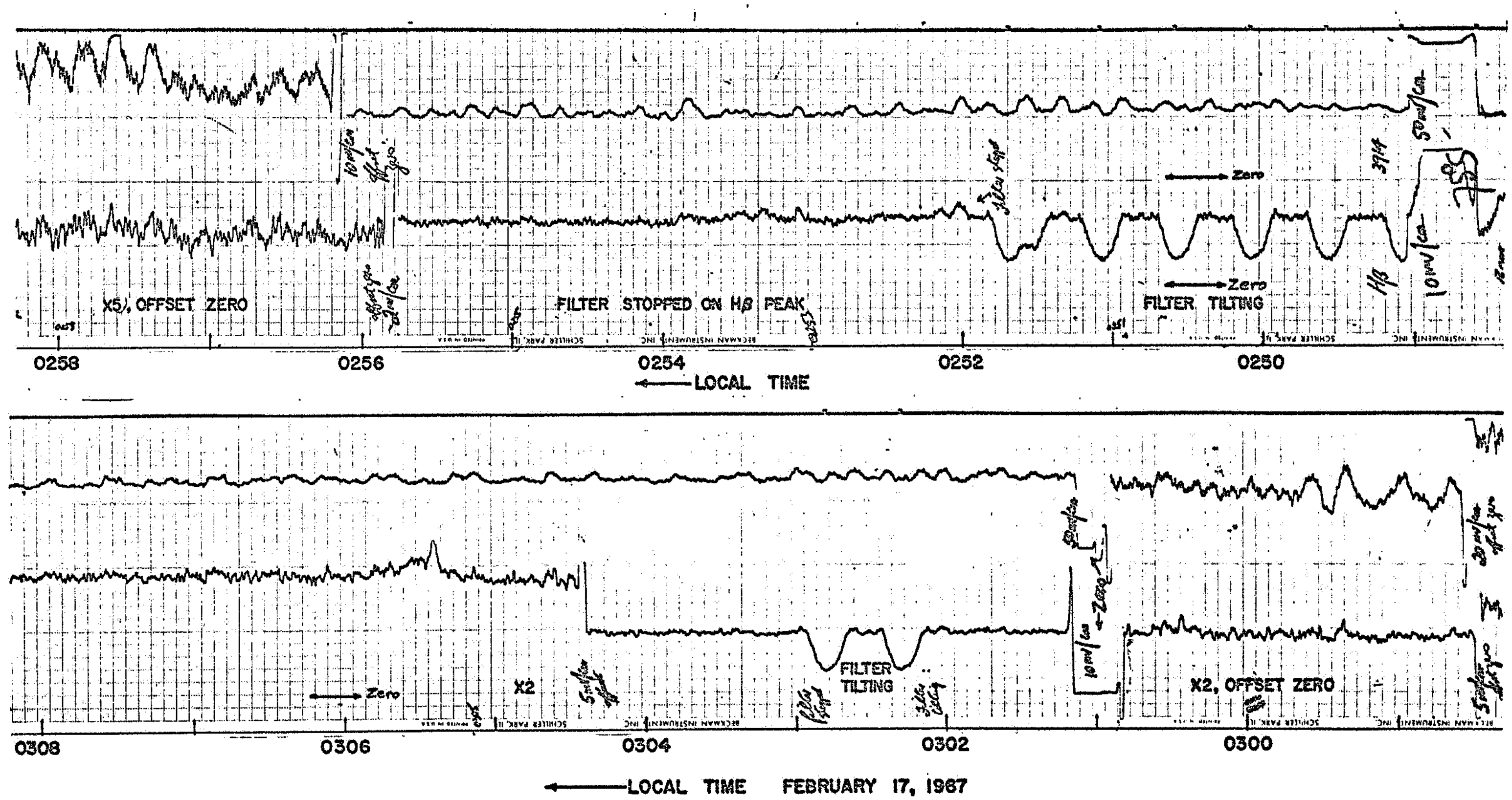
λ 3914 N_2^+
Hβ
X5, OFFSET ZERO
FILTER STOPPED ON Hβ PEAK
FILTER TILTING
Zero
0258
0256
0254
0252
0250
LOCAL TIME
X2
FILTER TILTING
X2, OFFSET ZERO
0308
0306
0304
0302
0300
LOCAL TIME FEBRUARY 17, 1967

FIGURE 3

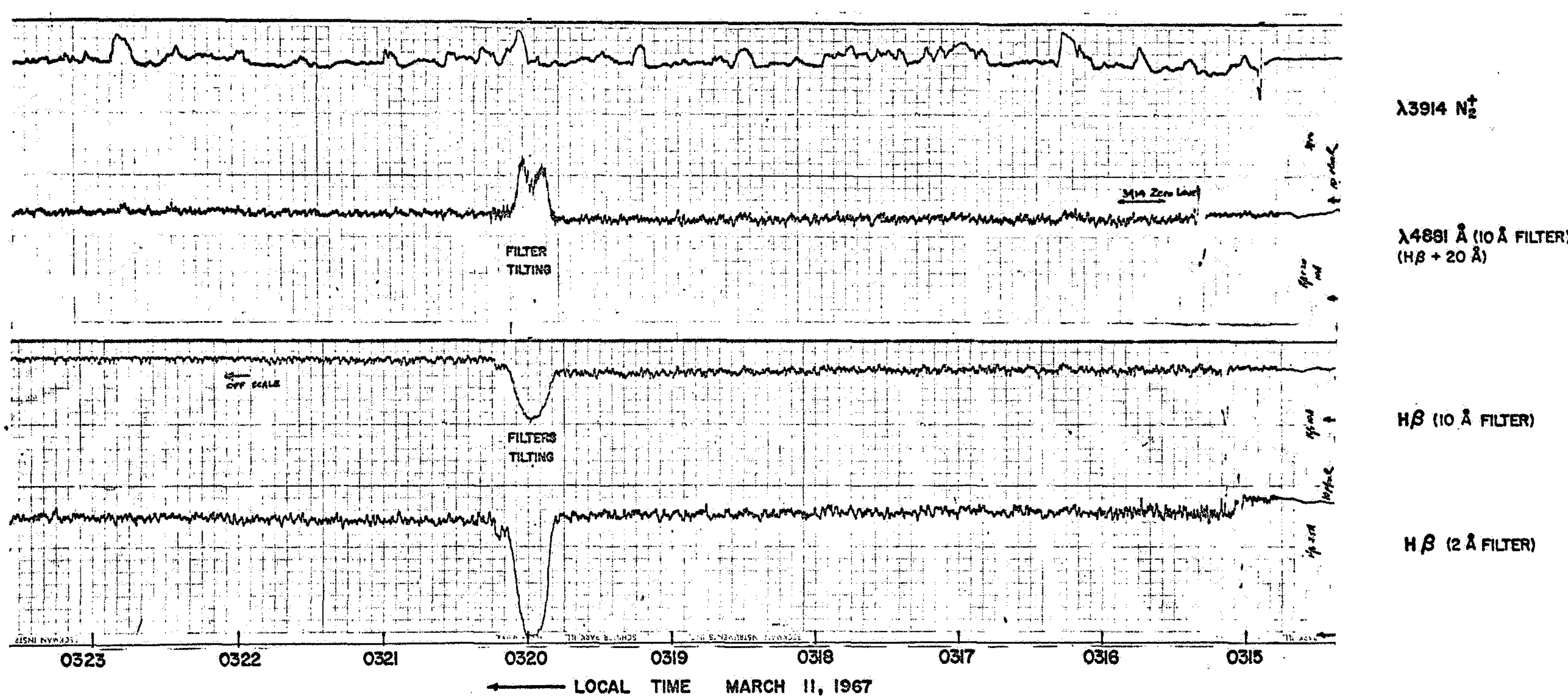
λ3914 N_2^+
λ4881 Å (10 Å FILTER)
(Hβ + 20 Å)
Hβ (10 Å FILTER)
Hβ (2 Å FILTER)
FILTER TILTING
FILTERS TILTING
OFF SCALE
0323
0322
0321
0320
0319
0318
0317
0316
0315
LOCAL TIME MARCH 11, 1967

FIGURE 4

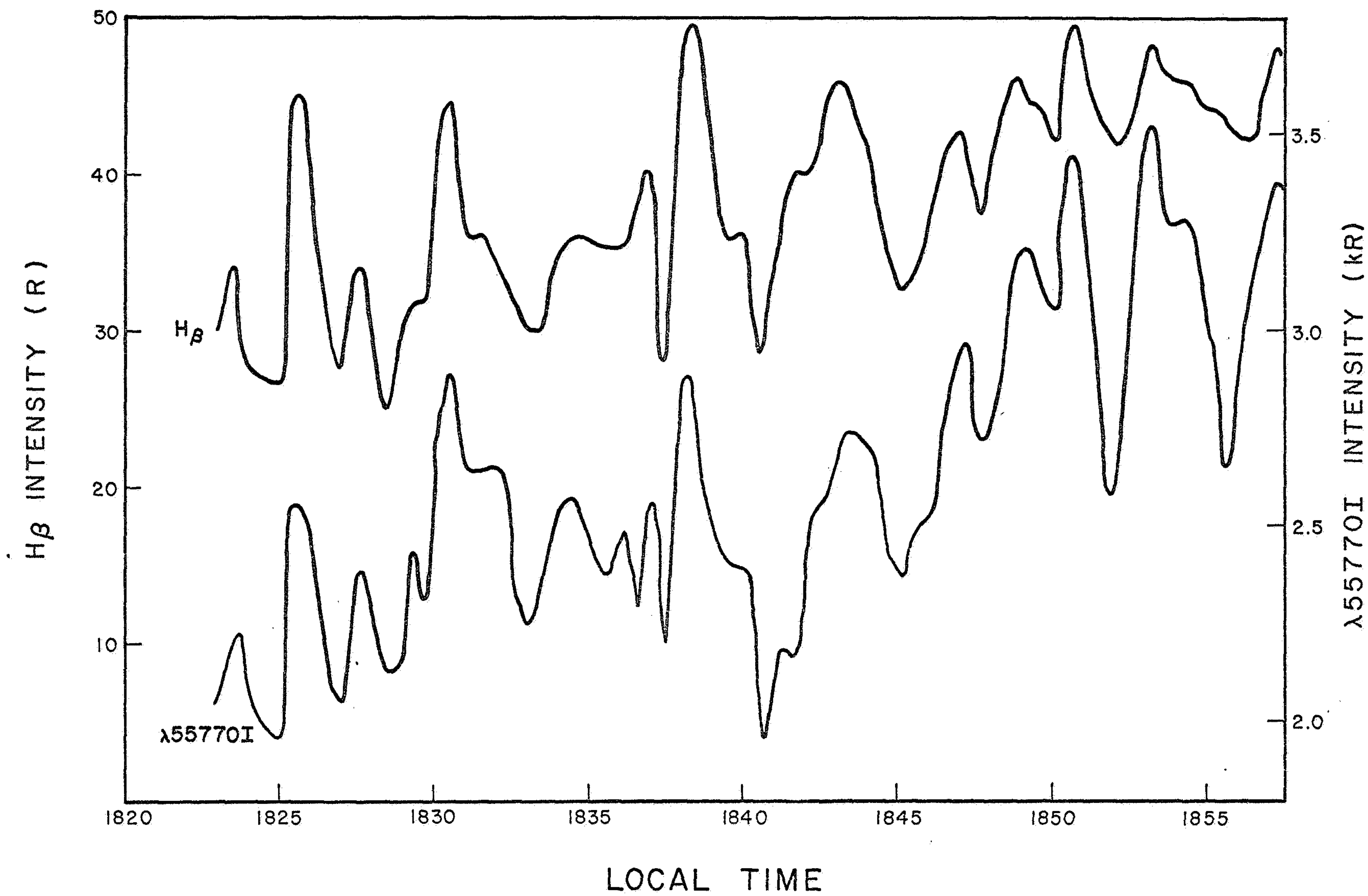

FIGURE 5

201339