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Electron Energy Estimations in an Auroral Arc

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Abstract. An arc-like auroral form passed over the magnetic zenith at Kilpisjärvi (69.02 N, 20.86 E), Finland, on 31st January 2001. The form was measured by a zenith photometer at Kilpisjärvi and by a scanning photometer at Karesuvanto about 100 km Southeast from Kilpisjärvi.

The form is studied in terms of rotational temperature in order to estimate energies of precipitating particles causing the emissions. The zenith photometer is used to clarify the total flux of the electrons and effective emission height, whereas the scanning photometer gives the intensity distribution over the height.

1 Introduction

The estimation of the energy of precipitating electrons from photometer data may be done by several methods. Maybe the most commonly used are ratios of two emission line intensities like the ratio between red 630.0 nm and blue 427.8 nm emissions. The energy dependence of this ratio is based on different distribution of the emissions over the height of the auroral form.

Another method is to use the atmospheric temperature to find out the altitude where auroral emission arises. That altitude depends on the energy of precipitating particles. Monoenergetic beam produces a characteristic emission distribution over the path of the precipitating beam. More wide energy spectrum makes up an emission distribution convolved from distributions of several monoenergetic beams.

Scanning the auroral form from the side gives the distribution of the emission intensity over the height of the form. Determining the temperature at the emitting volume fixes, together with atmospheric models, the altitude scale. That makes it possible to determine definite altitude distribution of the auroral form even from a data of a single scanning photometer.

The zenith photometer measures the integral intensity along magnetic field-line. The total amount of emissions depends on the number of precipitating particles and the energy flux carried by them. The integral column intensity of the 1NG nitrogen band describes well the total energy flux independently of the characteristics of the precipitation (Lummerzheim et al. 1994, Kastings et al. 1977). Thus the total energy flux may be estimated. The temperature measurement is distorted as emissions from different temperatures sum up nonlinearly when measurement is performed along the field-line.

Photometric measurements of the rotational temperatures have been done along magnetic field line (Holma et al., 2000, Kaila et al. 1989, Koehler et al., 1981, Vallance Jones et al., 1987). This is an attempt to get more information of the precipitating electron population by using two photometers.

2 Rotational temperature

The rotational temperature refers here the temperature measured from the spectral shape of the $N_2^+ 1NG(0,1)$ rotational band emission. This temperature is taken as the neutral temperature at the height of the emission. (i.e. the thermal equilibrium state is assumed) The neutral temperature is characteristic to the height (Henriksen 1987, Vallance Jones 1974). The temperature-height scale is modelled using MSIS-E-90 model atmosphere (Hedin 1991). Ionisation profile of the precipitating electron beam is characteristic to the energy of the electrons (Rees 1963). Profiles for different energies are calculated. The height information is then compared to the ionisation caused by precipitating electrons with different energies. Thus the energies of the electrons have been estimated. The rotational band arises when nitrogen ions are relaxed after ionization and excitation by precipitating electrons. Emission band is result of electron-vibration-rotation transitions of $N_2^+ 1NG(0,1)$. The shape of the emission shows the occupation distribution of the rotational states in the ion (and the neutral). This distribution varies as Bolz-

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Table 1. Specifications for the rotational temperature channels of the photometer at Kilpisjärvi.

Filter	Wavelength	Halfwidth
P-peak	427.79 nm	0.842 nm
R-peak	426.72 nm	0.891 nm
R-tail	425.66 nm	0.595 nm

mann distribution.

$$N = N_0 \cdot e^{-[K(K+1)C/kT]}, \tag{1}$$

where K is rotational number of the initial state, N is the total number of molecules at the initial (electronic-vibrational) state and N_0 the number of the molecules at the rotational state K, C is a constant, k is the Bolzmann constant, and T is the temperature. The constant C includes all rotational constants (Hertzberg 1950, Lofthus and Krupenie 1977).

The shape of the rotational band can be obtained with a multichannel photometer. It is possible to find optimal wavelengths for narrow band interference filters to have ratios of intensities through those filters to characterize the shape of the rotational band, and thus the respective temperature (Hunten et al. 1963). The peak wavelengths of the filters have been chosen to give good signal while maintaining proper sensitivity to temperature. With these selections we get a good signal to both filters and have satisfactory behaviour of the ratio through 200 - 700 K at least. We have used three filters (channels) called P, R-peak and R-tail channel describing the location of the transmission curve on the rotational band.

3 Instrumentation and measurements

The measurements were performed at Kilpisjärvi (69.02 N, 20.86 E) and Karesuvanto (68.47 N, 22.44 E) on January 31st 2001 22:22 - 22:25 UT. Photometer measurements were done by a scanning six-channel photometer that has been designed by K. Kaila et. al 1987 and revised in 1992 (Kaila et. al 1987). Three of the channels were used for rotational temperature measurements. The photometer uses bialkali photomultiplier tubes in rotational temperature measuring channels. The wavelengths to be measured are chosen with interference filters. The photometer is operating in pulse counting mode and controlled by PC. Timing is based on GPS clock, but during the measurement period the time has been taken from the PC clock. Integration times may vary from 0.05 seconds (or even less) upwards. The photometers have a field of view of about 0.6 degree. Measurements at Kilpisjärvi were done towards the magnetic zenith and at Karesuvanto scanning the vertical plane joining the two measurement stations. The integration time was 0.2 seconds on both instruments. The absolute intensities are not needed to clarify rotational temperatures as only ratios of intensities are used. However, the photometer has to be calibrated to get comparable values for the intensities of the P and R-branch channels (Kaila et al. 2000). The specifications for the channels used in measuring the rotational temperature are shown in the table 1.

Figures 1 and 2 show the relative intensities, ratios of intensities through R-tail and R-peak channels and the rotational temperature derived from the ratio for the Karesuvanto and Kilpisjärvi photometers respectively.

For the total energy flux the absolute intensities of the zenith photometer at Kilpisjärvi have been presented in the figure 3. There was malfunction in P-channel in the Kilpisjärvi photometer. Thus only curves for the R-peak and R-tail channels make sense in the figure.

4 Results and Conclusions

The temperature results for the zenith measurements at Kilpisjärvi and scanning measurements at Karesuvanto are presented in lowermost panels of figures 1 and 2 respectively. The temperature data are very noisy whenever there is a low intensity in the field of view. That is due to noise in the two datasets. Both of them has a pulse rate close to zero and the noise comes as square root of the pulse rate.

The zenith photometer at Kilpisjärvi shows a clear temperature minimum at 22:23:20. The efficient temperature minimum is 320 K and that relates to the maximum intensity height of 117 km according to the calculated ionization and emission profiles for precipitating electron beams with different energies. The scanning photometer at Karesuvanto shows the temperature of the lower border of the arc to be 240 K, which relates to 110 km. The shape of the intensity versus height from the scanning photometer differs from the intensity produced by purely monoenergetic electrons. It is even slightly double peaked, which could be produced by two electron populations with different energies. The energy of the main population electrons, assumed monoenergetic, is estimated to be about 6 keV.

The maximum column intensity of the blue line along field line at Kilpisjärvi is approximately 6 kR according to the values of both R-peak and R-tail channels. That indicates the total energy flux of the electrons to be 150 $\mathrm{mJ/cm^2 s}$.

The results from the photometers correspond promisingly well to each others. The efficient temperature is higher than temperature at the lower border af the arc as it should be. The measured difference of 7 km between peak and lower border is consistent with modelled results within uncertainty of the measurement. The modelled difference between these two heights is 4 – 5 km. These results are derived from calculated emission profiles for different energies, from which the column intensities are calculated for all the three channels of the zenith photometer.

This study showed an example of using pure photometric data to examine the energetic properties of auroral electrons. It is also possible to recognize the characteristics of the energy spectrum of the precipitating electrons. In this study the energy spectrum itself is still to be determined. In determining the total electron flux, there arose difficulties due to the failing P-channel. The P-channel measures more straightly the intensity of the whole band, but without it the total band intensity had to be calculated indirectly from

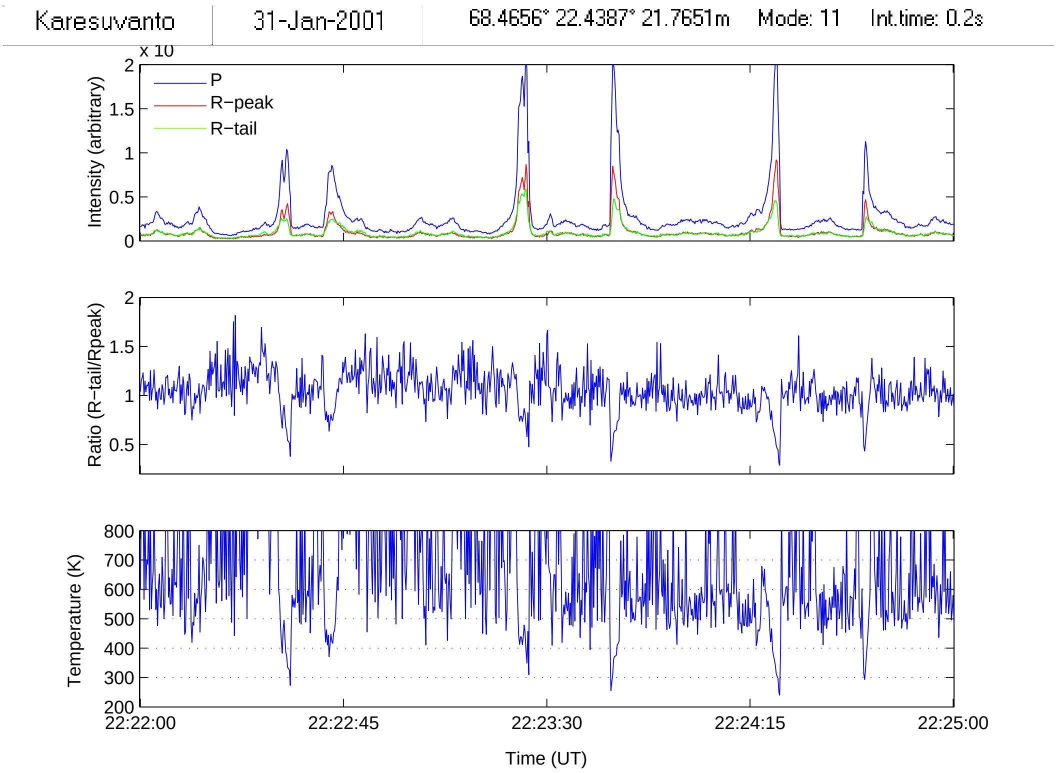

Fig. 1. The relative intensities of the three channels (uppermost panel), the ratio of the intensities through R-peak and R-tail channels (middle panel) and the rotational temperature measured at Karesuvanto by a scanning photometer. The studied auroral form is at the magnetic zenith in Kilpisjärvi at 22:22:50 – 22:23:30. The temperature data is very noisy when photometer is not pointing to bright features.

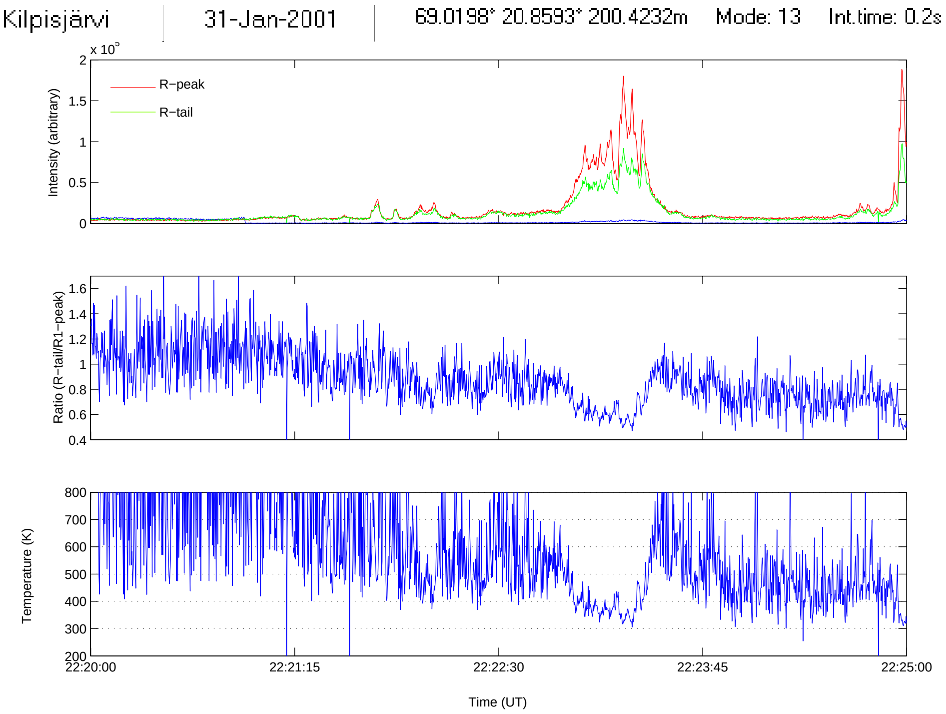

Fig. 2. The relative intensities of the three channels (uppermost panel), the ratio of the intensities through R-peak and R-tail channels (middle panel) and the rotational temperature measured at Kilpisjärvi by a zenith photometer. The P channel is very low due to a malfunction in the instrument.

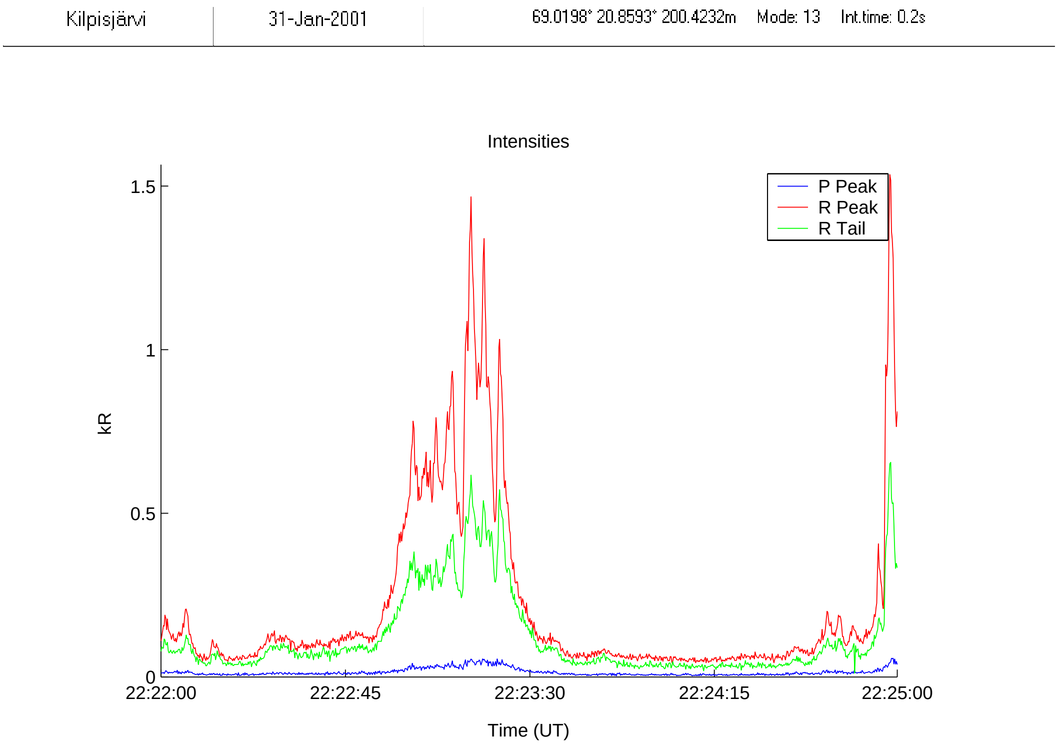

Fig. 3. The absolute intensities through R-peak (red curve) and R-tail (green curve) measured by the zenith photometer at Kilpisjärvi. The R-peak filter transmits about 25 and R-tail about 14 percent of the total band intensity. Exact numbers depend on the temperature.

the two R-channels. The study will continue with some improvements to details of the calibrational data handling and closer examination of the energy specrum of the precipitating electrons.

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