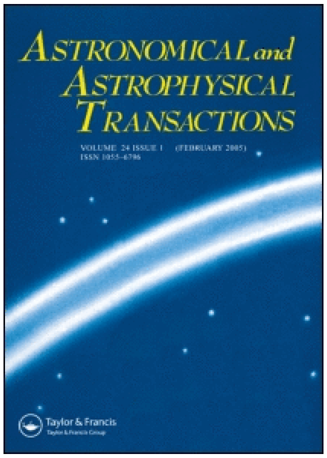

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CCD OBSERVATIONS OF THE SUN AT THE BALMER AND PASHEN CONTINUA

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The preliminary results of the solar CCD observations of the Balmer and Pashen continua and of the Balmer precontinuum are presented. The Balmer precontinuum intensity distribution for the emission features of a.r. 7890 NOAA/USAF are obtained. The limits of electronic concentration in the plasma volume along the line of sight are evaluated for an emission feature from this a.r. Solar monitoring at the hydrogen series continua and precontinua appears to have considerable promise.

KEY WORDS Sun, Balmer and Pashen continua

1 INTRODUCTION

Additional information about the solar plasma can be taken from the observations of the Sun at the hydrogen series continua and precontinua (Kurochka, 1989, 1991, 1995). The solar surface regions emitting in the Balmer and Pashen continua correspond to the places of enhanced emission measure (ME) whereas the temporal changes of the radiation intensity are mainly caused by the electron density variations in the solar plasma. Such simple observations should permit us to obtain an idea about the electron density dynamics in the active solar regions (a.r.).

The solar observations in the Balmer and Pashen continua and Balmer precontinuum have been carried out at the Astronomical Observatory of Kharkov State University (AO KhStU, Ukraine) in 1994–1995 and the preliminary results are presented.

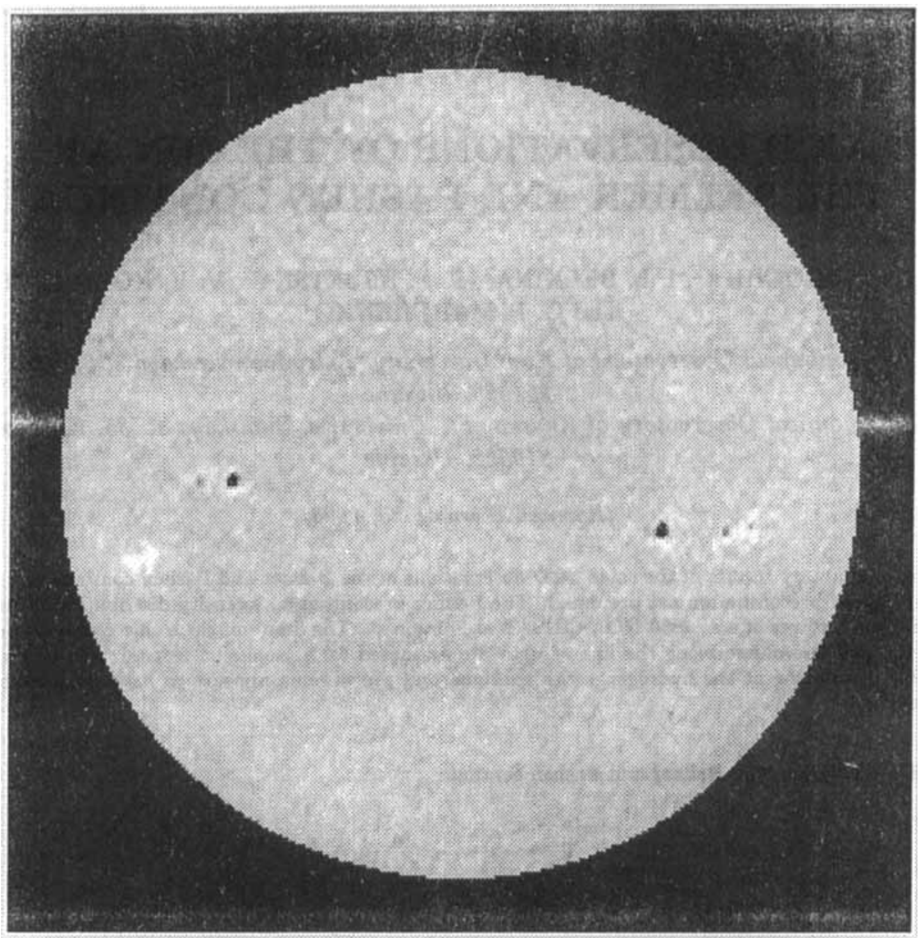
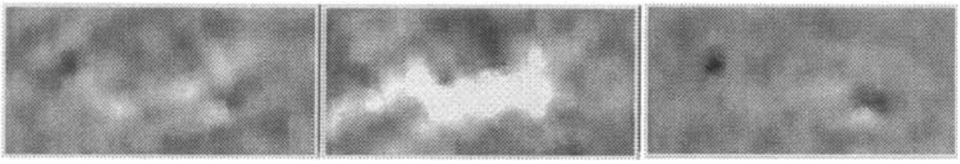


Figure 1 Balmer continuum Sun image taken on 1994, October 10, 10 h 50 m UT.

2 OBSERVATIONS AND RESULTS

The Sun was observed with the AO KhStU spectroheliograph (telescope aperture 100 mm, focal ratio 1/24) using a first order diffraction grid ($1200' \text{ mm}^{-1}$). A photometer with a cooled one-dimensional CCD, sensitive in the range from 3000 to 10 500Å, was employed. The instrumental photometric accuracy was 0.1% after the sensitivity inhomogeneity correction (Korokhin *et al.*, 1993). CCD photodiodes sampled the spectral part of $\sim$ 0.01Å width. The scale was 512 pixels per solar diameter ($3.5''$ pixel^{-1}) with a signal integration time of 0.128 s.

To obtain both the hydrogen continua and precontinuum images and exclude the effect of flocculus the spectral places without strong Fraunhofer lines were chosen. The solar images were registered at such wavelengths: 3638.7Å for the Balmer



a b c

Figure 2 The comparison of the a.r. 7890 NOAA/USAF Hc emission features with corresponding Hα and Hp-c pictures. Images for Hc (*a*), Hα (*b*), and Hp-c (*c*) were taken on 1995, July 19.

continuum (Hc), 8185Å and 8192Å for the Pashen continuum (Pc), and 3658.9, 3691.7, 3785, 3811.5, 3901.3Å for the Balmer precontinuum (Hp–c).

To study the evolution of active regions and compare their emissions in the various spectral parts, software permiting solar disk region images with given Carrington coordinates to be unfolded on the plane was used.

The features of the disk edge ($q > 60$) with the Hc enchanced emission correspond to the photospheric faculae. That is why we dealt with the emission features of the central zone of the solar disk ($q < 40$) only.

We obtained digitized images for 23 observational dates, and among them the image sets with the time intervals from 5 min to one hour between images for some dates.

The observations at both Hc and Pc have revealed that the highest contrast of the emission features (very seldom exceeding 10% at Hc) was recorded in the active regions with evolving groups of spots. No emission features were actually seen in the old spotless floculus regions. The contrast of the individual emission points is comparable with the net one and is equal to 1–1.5% of the mean quiet Sun.

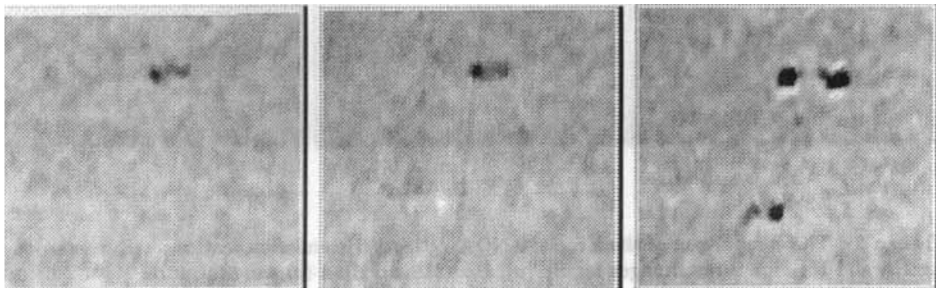
Figure 1 shows one of the Balmer hydrogen continuum solar images. The bright net with the size corresponding to the chromospheric one and the emission features among spot groups can be seen in this picture.

In Figures 2 the 7890 NOAA/USAF a.r. Hc-emission picture (heliographic coordinates: $\varphi = 6$ N–2 S, L=273–290) is compared with the corresponding Hα and Hp-c regions. Images were taken on 1995, July 19. Unfortunately we were unable to obtain Hc, Ha and Hp-c images simultaneously.

It is somewhat surprising that the places of strongest Hc-emission did not coincide with those of the Ha-alpha emission maxima. This non-coincidence has in fact been recorded for all active regions.

As can be seen from Figure 2(*c*) visibility of the emission features at the Balmer precontinuum (Hp-c $\sim$ 3691.7Å) is less that at the continuum (Hc $\sim$ 3638.7Å). The last fact is not typical, however. According to our observations the contrast fall with increasing wavelength is different for the various parts of the a.r. This suggests that the contribution from the regions with high Ne to the different solar surface parts is not the same.

The Pc-emission pictures actually coincide with Hc ones with their contrast being essentially less in Pc. This should be expected because the Balmer continuum



a b c

Figure 3 The appearance of new 7902 NOAA/USAF spots at a site of preceeding Hc emission feature. Hc pictures were obtained on 1995, August 23 12 h 10 m (*a*), 12 h 44 m (*b*), and August 24 09 h 15 m (*c*) (UT).

emission is brighter than the Pashen one by more than an order of magnitude, whereas the solar background emission is nearly the same there. The observational data show that the Pc feature contrast as a rule does not exceed 4%.

According to our observations Hc and Pc emissions rise in the evolving active regions where the new spots and pores are born. As Figure 3 shows, the appearance of the Hc emission feature is followed by the birth of new 7902 NOAA/USAF spots at the same site.

We have calculated the Balmer precontinuum intensity distributions for the emission features of a.r. 7890 NOAA/USAF (1995, July, 19). Data have been taken as a result of subtracting the intensity recorded at 3901.3Å from the total intensity at 3658.9, 3691.7, 3785, 3811.5Å. The 3901.3Å wavelength is far enough from the Balmer limit so that one can regard the emission as caused only by the continuum facula. The procedure of intensity standardization has been reported in Belkina *et al.* (1996).

Figure 4 shows the Balmer precontinuum intensity distribution for an emission feature from a.r. 7890 NOAA/USAF. Using this curve the Ne distribution in a volume occupied by the emission feature may be evaluated as follows.

It is well known that the higher the Ne in the emitting plasma the further the limit of the Balmer continuum (and other hydrogen series too) shifts to the red. This is evident from the Englesse–Teller formula and more accurate formulae (Kurochka, 1974; Kurochka and Ribko, 1978) accounting for the continuum limit shift caused by both the Stark and Doppler effects.

According to the above studies for the Balmer continuum a maximum of Ne is determined by:

$$n_{e\max} = 8.0 \times 10^{22}(m_{s+d} + 1)^{-7.5} - 1.6 \times 10^{6}(m_{s+d} + 1)^{-3}V^{3/2}. \qquad (1)$$

Here V is the most probable velocity of the hydrogen atŏms in cm s^{-1}, and m_{s+d} is the number of the line, discernible under the ultimate resolution. As in our case V is unknown, we let $V = 0$ for simplicity, i.e. neglect the Doppler effect. However, it

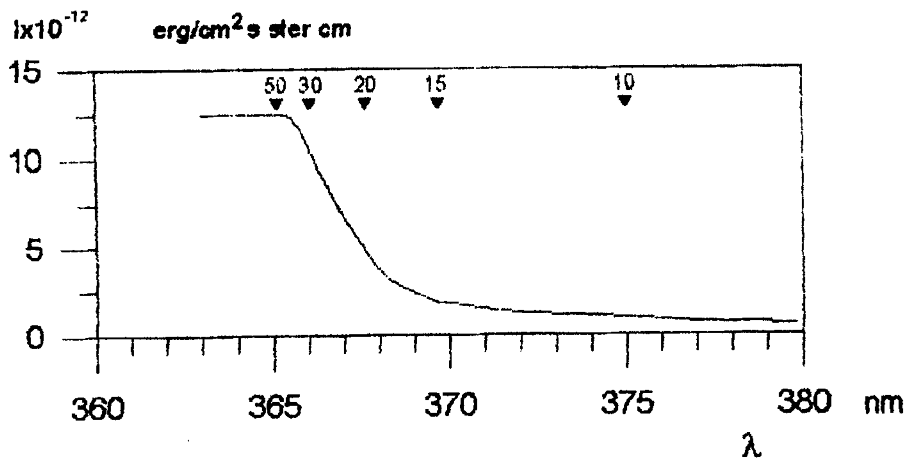


Figure 4 The Balmer precontinuum intensity distribution for an emission feature from a.r. 7890 NOAA/USAF.

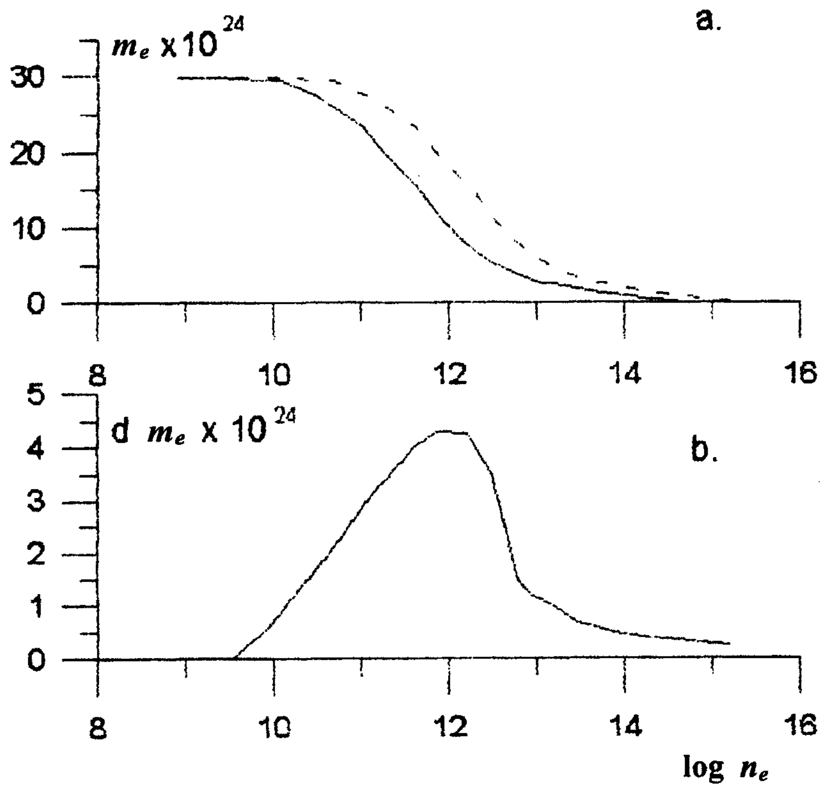


Figure 5 The emission measure (m_e) distribution for the emission feature of Figure 4; (a) integral m_e, (b) differential $d(m_e)$.

should be kept in mind that the higher the line number m_s the larger the error in the resulted n_e. Under this simplification n_e is connected with m_s by the well-known expression (Allen, 1973):

$$\log n_{e\,\max} = 22.7–7.5 \log m_s. \tag{2}$$

At the precontinuum the increase of intensity ($\Delta I_{\rm pc}$) from a line with a number k to the next $(k+1)$th one is caused by the increase of emission measure value:

$$\Delta m_e = 24 \times 10^{24} \cdot \Delta I_{c,0}. \tag{3}$$

For a chosen emission feature the m_e integral distribution (Figure 5(a), dotted line) has been constructed as a result of addition of the precontinuum emission intensities arising at the different n_e.

It should be noted that this distribution has been plotted without accounting for the existence of the intrinsic precontinuum existing even in a plasma with fixed electron concentration (Kurochka, 1974, 1995) as a result of overlapping the wings of the neighbouring emission lines. Taking account of the fact that for fixed n_e the continuum begins 3–5 line numbers before the (m_s+1)th line shifts, the distribution is represented by the dotted line in Figure 5(a) to the $\log m_e$ values less by 0.6 (Venglinsky, 1994), their shapes being kept. The corresponding integral distribution is given in Figure 5(a) as the solid line. This curve should be considered as more accurate than the previous one.

Figure 5(b) shows the differential m_e distribution for a chosen emission feature which suggests its main emission measure to be formed by volume with n_e ranging from 10^{11} to 10^{12} sm^{-3}.

3 DISCUSSION

It is shown that the emission features usually have low contrast at Hc and Pc (except the solar flares, possible). That is why solar monitoring at hydrogen series continua requires precise stable detectors – in particular, the cinematographic patrol is not appropriate because of its insufficient accuracy. Hc observations should be taken in the narrow spectral range to exclude the effect of the numerous strong metal lines. The Pc observations allow a wide band filter to be used.

As a rule the Ha-alpha and Hc emission maxima do not coincide spatially, which is due mainly to the different mechanisms of their emission. Ha emission is caused first of all by thermal mechanisms whereas the Hc one is a result of enhancing emission measure:

$$m_e = \int_0^L V n_e^2 T_e^{-3/2} dl. \tag{4}$$

Of course, the variations of the emission measure are determined by the object dimensions, L, and temperature, T_e also. However, as the parameter T_e changes only by a few times (from about 6000 to 20 000 K) in optical formations, whereas

n_e varies by some orders of magnitude, and $m_e \sim n_e^2$, thus changes of m_e (in time and in the plane) should be due to variations of n_e.

Either parameter n_e or L is more responsible for the m_e macroscopic variations and should be discussed separately (Kurochka and Kiryuhina, 1989; Kurochka, 1991).

If the plasma is n_e inhomogeneous enough the precontinuum may be extended from hundreds to thousands of angstroms with intensity increasing towards UV and containing the data about n_e irregularities at the subtelescopic level (Kurochka and Kiryuhina, 1989; Kurochka, 1995).

The volumes of plasma with the highest n_e give rise to continuos emission most removed from the theoretical continuum edge (3646Å). In an n_e inhomogeneous plasma the emission intensity at the precontinuum can rise toward the theoretical series limit. This is due to the fact that the plasma volumes with $n_e < n_{e\,\max}$ generate their own continua whose beginnings are closer to the theoretical limit for low n_e. Their superposition leads to the intensity increase of the continuous spectrum in the Balmer precontinuum towards the shorter waves because the optical thickness of the emission features is as a rule less than or much less than 1.

4 SUMMARY

We present the first results of a new kind of solar observations a in the Balmer and Pashen series continua and Balmer precontinuum. Such observations can provide valuable information about the n_e irregularities, processes occurring in the active regions and about the formation of areas with enhanced plasma density, which may be the precursors of solar flares. To obtain these data the nature of time variations of the plasma density should be studied in active regions.

References

Allen, C. W. (1973) *Astrophysical Quantities*, University of London.
Belkina, I. L. *et al.* (1996) *Kinemat. i Fiz. Nebesn. Tel* **12**, No. 2, 65.
Korokchin, V. V. *et al.* (1993) *Astronom. Vestnik* **27**, No. 3, 56.
Kurochka, L. N. (1967) *Astron. Zh.* **44**, 368.
Kurochka, L. N. (1974) *Astron. Zh.* **51**, 892.
Kurochka, L. N. (1989) *Issledovania Solnechnoi Plazmy*, Ashkhabad, p. 89.
Kurochka, L. N. (1991) *Kinemat. i Fiz. Nebesn. Tel* **7**, No. 4, 31.
Kurochka, L. N. (1995) *Solar Phys.* **156**, 65.
Kurochka, L. N. and Kiryukhina, A. I. (1989) *Pis'ma v Astron. Zh.* **15**, 82.
Kurochka, L. N. and Ribko, L. B. (1978) *Solar Phys.* **57**, 319.
Venglinsky, E. R. (1994) *Visnyk Kiev Univ. Astron.*, No. 6, 22.