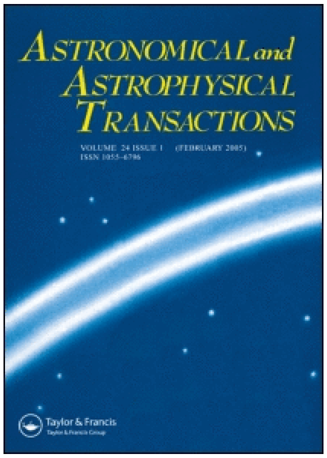

Astronomical & Astrophysical Transactions
The Journal of the Eurasian Astronomical Society
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713453505

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Online Publication Date: 01 August 1999
To cite this Article: Akimov, L. A., Beletsky, S. A. and Dyatel, N. P. (1999) 'The chromospheric D_3 helium emission observed during the total solar eclipse of July 31, 1981', Astronomical & Astrophysical Transactions, 18:1, 253 - 259
To link to this article: DOI: 10.1080/10556799908203063
URL: http://dx.doi.org/10.1080/10556799908203063

Astronomical and Astrophysical Transactions, 1999, Vol. 18, pp. 253–259
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THE CHROMOSPHERIC D_3 HELIUM EMISSION OBSERVED DURING THE TOTAL SOLAR ECLIPSE OF JULY 31, 1981

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(Received January 10, 1997)

The digitized images of 350 eclipse chromospheric spectra obtained with a special automatic photometer have been used to construct the image of the D_3 He I chromosphere over the range of 36°N–42°S in latitude. The chromospheric emission comes from two very irregular bands with peaks of intensities at heights of 1100–1700 km for the bands with the dominant emission, and at a height of around 300 km for the lower bands.

The distribution of the surface brightness averaged over all measured latitudes (36°N–42°S) versus height also reveals two peaks. The energy emitted by the upper layer is determined to be seven times larger than that emitted by the lower one.

The chromospheric D_3 emission is well correlated with the emission of the green corona (503.3 nm) at low heights. The correlation disappears at heights of more than 1500 km. The chromosphere above active regions and spots is lower. It is supposed that such behavior is caused by large-scale magnetic fields of the Sun and by structural elements, such as spicules and fibrils.

KEY WORDS Sun, chromosphere, eclipse, helium emission

1 INTRODUCTION

The study of the helium emission in the solar chromosphere is of importance because of its connection with the radiation of the corona. Besides, it provides a simple ground-based method for observing the limb passage of holes. The D_3 helium line (587.6 nm) is the most intensive line of flash spectrum during total solar eclipses.

The analysis of the D_3 helium data obtained from the cinematographic observations of the flash spectrum with a slitless spectrograph during the total solar eclipses of September 22, 1968 and July 10, 1972 is given in (Akimov *et al.*, 1997, here after referred to as Paper 1). It was found that the characteristics of the chromospheric helium emission in both eclipses are basically similar, though there are some differences. The helium emission concentrates in the layer observed above the limb with peak intensity at heights of 1200–1700 km; many regions give an emission with a peak near the photosphere; the D_3 emission varies along the latitude strongly, and the absolute values of the emission differ for the 1968 and 1972 eclipses.

Similar cinematographic observations of the helium D_3 chromosphere were performed during the eclipse of July 31, 1981. However in this case, the reduction of the flash spectra is quite different from that of the 1968 and 1972 eclipses.

One of the purposes of this paper is to demonstrate how an image of the chromosphere can be constructed in spectral lines from intensity measurements of flash spectra obtained during eclipses. To this end an automatic photometer was constructed by one of the authors.

2 INSTRUMENTATION AND DATA PROCESSING

Spectrogram movies of the flash spectra were obtained during the total solar eclipse of July 31, 1981 using a 10 cm slitless spectrograph with a diffraction grating 600 mm^{-1}, 10×10 cm, and recording the images on KN-2 film with 20 exposures per second ($\sim$ 20 km intervals in the chromosphere). The times of exposures were registered with high accuracy. The observations were carried out to a 20 s interval before totality and extended to a 30 s interval following totality. The spectrograms obtained at the eclipse cover the wavelength range of 40 nm including D_3 He I (587.6 nm) and D_1, D_2 Na I (589.0 and 589.6 nm). The linear dispersion on spectrograms is 18Å mm^{-1} for the first order.

The instrumentation and standardization were similar to those used for the eclipse of July 10, 1972, and we refer to (Livshits *et al.*, 1976; Akimov *et al.*, 1982) for details.

The measurements of spectra reported here were performed with an automatic photometer designed for image scanning with high frequency (750 steps per second). The scanning step is 10 μm in both coordinates which corresponds to one second of arc on the solar surface. The slit size of the photometer was chosen to be 12×20 μm.

The signals from the photomultiplier of the photometer are amplified by a flat-staggered integrated amplifier with an integration time of 0.67 ms controlled by a quartz generator before being sent to a 14-bit analogue-digital converter, and are then entered into a Iskra 1030 M computer.

To obtain the final data from digitized images of 350 spectra of the west limb we developed some algorithms, and created software including the following stages:

(1) conversion of digitized photographic densities into intensities;

(2) determination of the background intensity (photosphere) for every spectrum;

(3) determination of boundaries of D_3 He I and D_1, D_2 Na I lines;

(4) integration of intensities in the line boundaries;

(5) matching of successive spectra;

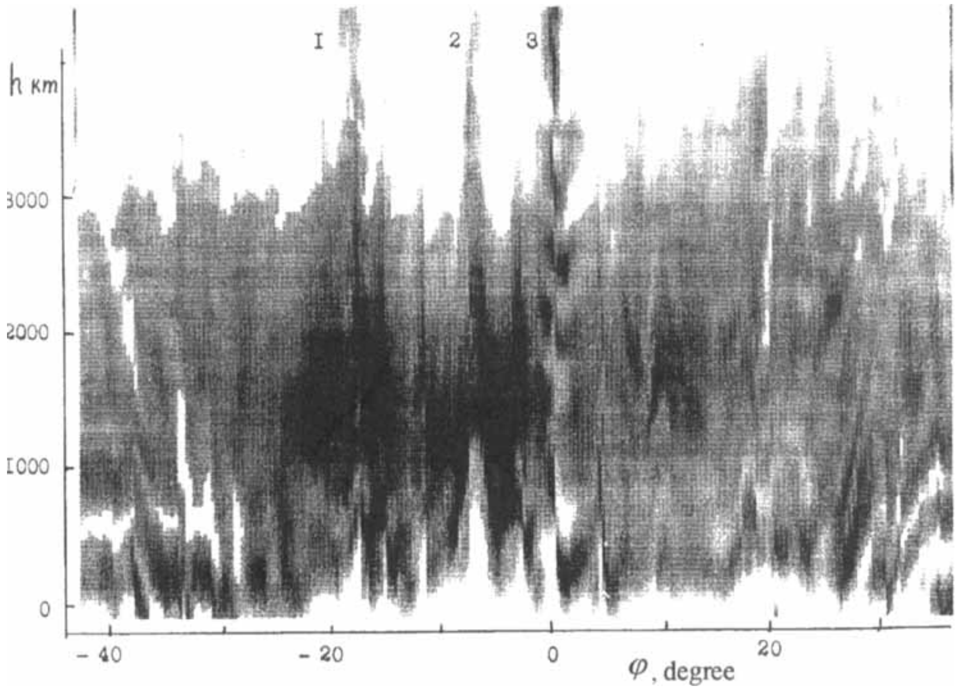

Figure 1 Chromospheric helium emission as seen in the D_3 emission line on the west limb during the eclipse of 31 July 1981. *1,2,3* are prominences. Dark places correspond to the more intense emission.

(6) construction of a two-dimensional file (in FITS-format) of the integral brightness distribution in both time and coordinates along the limb;

(7)smoothing of integral intensities, and their differentiation in the direction of dispersion;

(8) construction of images in the "time-position angle" system;

(9) determination of a zero-point of heights from measured intensities of the photosphere;

(10) construction of a FITS- file of the surface brightness in the "height–position angle" system.

3 RESULTS AND DISCUSSION

After the above processing procedure we obtain the surface brightness of the D_3 chromosphere versus height and heliocentric latitude (see Figure 1). The image

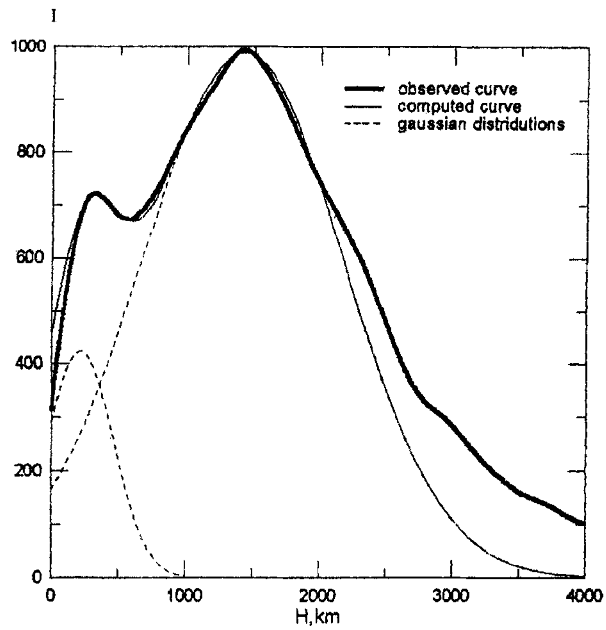

Figure 2 Variation of brightness averaged over latitude with height.

demonstrated in Figure 1, is similar to those obtained with universal birefringent filter (see, for example, Koutchmy, 1994). In Figure 1, dark places correspond to the more intensive emission. Three prominences are clearly seen. The west limb at the moment of eclipse was disturbed by active regions and spots, by old faint plages and prominences. The activity was concentrated in the equatorial zone (25°N–25°S).

In Figure 1 one can see two very irregular emission bands separated by a dark band, with the intensity peaks at heights of 1100–1700 km for the band with the dominant emission, and at a height of about 300 km for the lower bands. The emission is much more pronounced in the range of the equatorial zone with high activity. The upper boundary of the helium emission is lower above the spots and active regions. These results are in agreement with our previous investigations of the eclipses of 1968 and 1972 (Paper 1).

It is possible to estimate the energy contribution from both layers seen in Figure 1. For this purpose we use the distribution of the surface brightness, I, averaged over all measured latitudes (36°N–42°S) shown in Figure 2. This distribution also reveals two peaks. We suppose that the observed energy distribution can be presented by a sum of two Gaussians:

$$a_1 \exp\left(-\frac{(h-h_1)^2}{2\sigma_1^2}\right) + a_2 \exp\left(-\frac{(h-h_2)^2}{2\sigma_2^2}\right),$$

where the subscripts 1 and 2 refer to upper and lower layers respectively. The parameters are chosen to fit the curve presented in Figure 2.

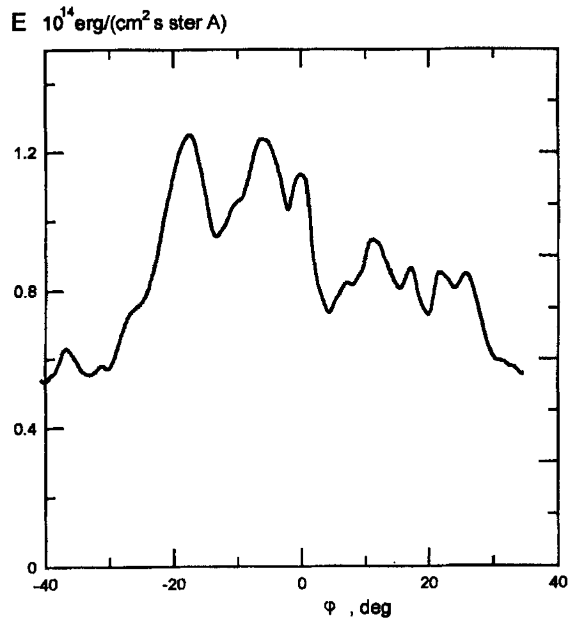

Figure 3 Integral emission versus latitude.

This procedure gives the following values:

$$a_1 = 660,\ a_2 = 282,\ \sigma_1 = 750,\ \sigma_2 = 250,$$

and $h_1 = 1425$, $h_2 = 215$, where h_1 and h_2 are the heights of emission peaks for the upper and lower layers, respectively. Using these parameters we obtain that the total emission of the upper layer is seven times larger than that of the lower layer.

So we see that the upper emission layer provides the major contribution to the D_3 chromospheric emission observed, with the remainder of the emission coming from the lower layer.

On the basis of data obtained one can study the properties of the helium chromosphere as a whole, considering the Sun as a star. The total energy emitted by the helium chromosphere in D_3, in the range 36°N–42°S latitude in our case, may be used to study variations of D_3 emission with the cycle of the solar activity.

Now we consider next the characteristics of the helium emission. Figure 3 shows the variation of the integral helium emission E (surface brightness integrated radially above the limb of the Moon) with latitude. We see again that the dominant emission in D_3 comes from the equatorial zone where the solar activity is circulating. The value of emission above active regions is 1.5–2 times greater than that in the normal chromosphere in the equatorial zone. The results are in good agreement with those for the 1968 and 1972 eclipses (Paper 1).

Adopting the emission mechanism for the triplet lines of helium in terms of photoionization by coronal EUV it is interesting to compare the D_3 integral brightness

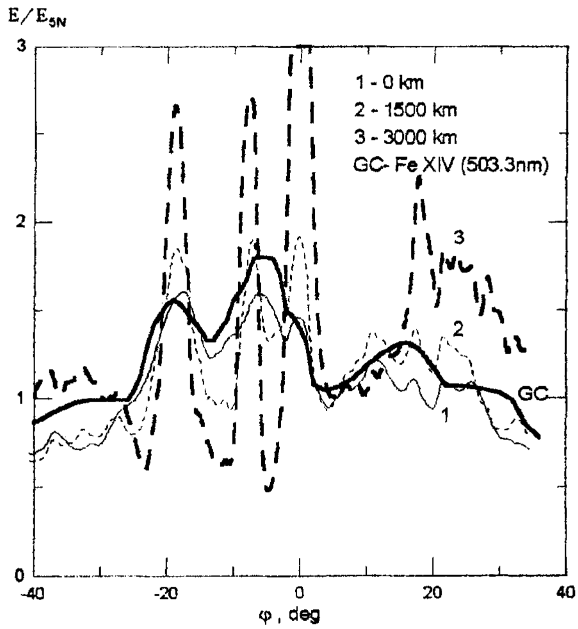

Figure 4 Comparison of the integral D_3 chromospheric emission at heights of 0, 1500, 3000 km with the intensity distribution of the green corona.

distribution with the intensity distribution of the green corona (503.3 nm) taken from Solar Geophysical Data (1981). Such a comparison is shown in Figure 4. The integral brightness distribution normalized to the point with $\varphi = 5°$N are plotted for $h = 0$, 1500, 3000 km. The intensities of the green corona emission are also normalized to this point. We see that the D_3 emission follows the intensity of the corona, with dominant emission in the zone of active latitudes up to $h = 1500$ km. After $h = 1500$ km the behaviour of the D_3 emission changes. At a height of 3000 km we do not see the dominant emission in D_3 (excluding prominences) above the strong active region (0°–25°S), moreover, it is less than that of the normal chromosphere. The D_3 emission above the old faint plage is enhanced significantly. The connection of the D_3 emission in the chromosphere with the intensity of the green corona was also studied from the eclipse of 1972 (Paper 1). Both results are in good agreement.

We suppose that in the low chromosphere, which is rather uniform, both the helium emission and the corona emission are caused by the large-scale magnetic fields of the Sun. The peculiarities of the helium emission at heights of more than 1500 km are due to chromospheric structures, such as spicules for the normal and slightly disturbed chromosphere, and mostly horizontal elements (fibrils) for the active chromosphere. The magnetic field above the active regions lowers the chromosphere. In the normal chromosphere the magnetic fields are mainly radial, and they enlarge the boundaries of the chromosphere.

We have not considered the mechanism of the helium emission. The mechanism for the helium emission in the middle chromosphere is well developed in many papers (see e.g. Nikolskaya, 1966; Hirayama, 1971; Gulyaev, 1972; Zirin, 1975; Livshits, 1975; Marsh, 1977; Avrett and Koutchmy, 1989).

Explanation of the helium emission near the base of the chromosphere in terms of photoionization of He I by coronal EUV meets great difficulties. This question must be treated separately.

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