SEARCH AND INVESTIGATION OF COLD EMISSION IN THE SOLAR CORONA OF AUGUST 11, 1999

G. Yakunina, O. Smirnova, A. Delone, A. Gorshkov, G. Porfir’eva
Sternberg Astronomical Institute, Moscow, 119899, Russia
(Received July 22, 2002; received in final form September 22, 2002)

The cold coronal emission was revealed during the interferometric observations of the solar eclipse. The emission weak lines of Hα 6563 Å and K CaII 3933 Å and the coronal line Fe XIV 5303 Å were used. The cold region was inhomogeneous by its characteristics. Temperature and motions were determined in it.

Key words: Sun, corona, plasma motions.

PACS number(s): 96.60.Pb

The solar corona is known to be a hot plasma phenomenon with the electron temperature $T \gtrsim 1 \times 10^6$ K and low density $n_e \leq 10^{-8}$ cm$^{-3}$. It is observed in lines of high ionized elements in wide spectral region. The strongest coronal lines in the visible spectrum are the lines of Fe X ($\lambda$ 6374 Å), Fe XIV (λ 5303 Å), and Ca XV (λ 6374 Å) with $T \approx (1-3) \times 10^6$ K. However, since 1868, a faint Hα-emission in the corona, having $T \approx (10^4-10^5)$ K, has been observed more than once during and out of the solar eclipses from the Earth. A review of the results of the cold corona investigations is given in [1]. Successful observations of the cold corona were also obtained in [2-4]. Modern X-ray and EUV space observations also show that the corona is very dynamic and inhomogeneous by its structure [5].

The aim of this investigation was to search the cold coronal emission during the solar eclipse on August 11, 1999 and to detect its temperature. The observations were carried out in Bulgaria on the Black seashore. A horizontal solar instrument, consisting of two coelostat mirrors, feeding two parallel tubes with identical optical and signal registration systems, was used to photograph the solar corona in three wavelengths. This installation, assembled in Sternberg Institute, was exploited for the first time during the observations in August of 1999. The Fabry-Perot interferometers for the Hα, K CaII and Fe XIV lines together with the corresponding interference filters were employed, two of them were replaced consequently in one tube. The interference filters with the full widths of 15 Å for the Fe XIV and Hα lines and 40 Å for the K CaII line were used as the premonochromators. The observations, instrument and the method of the treatment are described in more details in [6].

Fig. 1. Schematic drawing of the location of the prominences (a) and Hα, 10 s (b), and K CaII, 10 s (c, d) interferograms of the solar corona during the eclipse on 11 August, 1999. CCE is the cold coronal emission. The north is on the top and the west is on the left.
The negatives were digitized and the conversion into the intensities was performed by using the characteristic curve approximated by a ratio of polynomials. In Figure 1 a schematic drawing of the locations of the prominences, seen in Hα (according to data from Internet and observations on Crimea observatory on August 11), and interferograms in two λλ are shown. For the convenience the prominences were numbered. The numbers on the interferograms (Fig. 1 b, c) indicate approximately the position angles of the corresponding prominences. The differences between the locations (or intensities), seen in Hα and K Ca II, are possibly caused by differences of the time moments during the full eclipse phase. K Ca II interferogram was photographed in the first half of the totality and Hα, and green ones were photographed during the second half of the eclipse, when the west prominences became visible.

The emission on the Hα and K Ca II interferograms has been revealed to be more intense in the places, where Hα-prominences were situated, but there were the interference rings in the site CCE (Fig. 1 b, c), where no prominence was observed. We consider these regions as those of the so-called “weak Hα-emission” and named them “CCE” (cold coronal emission). The Hα and K Ca II CCE-s coincide by their locations. We believe that these CCE-s can not be artificial images caused by some light scattering in the instrument, because the Hα and K Ca II interferograms were taken independently on the different optical tubes and with different inclinations of the corresponding interference filters and Fabry–Perot interferometers. In Figure 1 d the K Ca II CCE is shown in a larger scale. A fine structure is distinctly seen.

The centers of the Hα and K Ca II interferograms were found to be correspondingly near the prominence 4 (Fig. 1b) and in the centre of the solar disk (Fig. 1c), that is why the Hα and K Ca II interference rings are turned relatively to each other in the CCE region. But we believe that we see the same coronal bulk in the Hα and K Ca II lines and consider the mean characteristics over this volume. Using a special program of treatment, about 16 radial cross-cuts from the centres of the interferogram pictures through the more intense K Ca II details and at the same Hα sites were made and 62 and 69 line profiles of different coronal features were obtained correspondingly in Hα and K Ca II. The Doppler widths ΔλDobs of the line profiles and shifts with respect to the average ring positions were measured, which allowed to investigate the motions in the coronal plasma. The observed widths ΔλDobs were corrected for the instrumental broadening. The corrected Doppler widths ΔλD of an optically thin line is related to the temperature T and turbulent velocity ξ by the equation

\[
\frac{\Delta \lambda_D}{\lambda} = \sqrt{\frac{2kT}{M_i} + \xi^2},
\]

where \(M_i\) is the mass of the ion producing the line emission, \(k\) is the Boltzmann constant, \(c\) is the speed of the light, and \(\lambda\) is the standard wavelength of the emission line.

The turbulent velocity \(\xi\) is the excess amount of the observed line width over the thermal contribution \(v_{th} = \sqrt{\frac{2kT}{M_i}}\). The bigger \(M_i\) is the smaller the thermal contribution is. The relations between \(\Delta \lambda_D\) and \(\xi\) were calculated for the Hα and K Ca II lines. A set of the temperatures from \(10^4\) K to \(2 \times 10^5\) K was used. The Doppler width \(\Delta \lambda_D\) against the \(\xi\) for the two lines considered is plotted in Figure 2 a, b. The various temperature curves almost do not differ for the Ca II line, except the small \(\xi\) range, but they differ noticeably for the Hα-line. We suppose that we observed the same coronal bulk both in the Hα and K CaII lines and that Hα and K CaII corona had almost equal mean \(T\) and \(\xi\), implying the mean values over the CCF-volume.

![Fig. 2. The Doppler width ΔλD against the turbulent velocity ξ for the K CaII (a) and Hα (b) lines for different temperatures given in K.](image)
For the K CaII line the Doppler widths $\Delta \lambda_D$ change from 0.23 Å to 0.46 Å with the $\Delta \lambda_D = 0.30 \, \text{Å}$, yielding the velocity $\xi$ changing in the range from 17 km s$^{-1}$ to 28 km s$^{-1}$ and the $\xi = 20 \, \text{km s}^{-1}$ accordingly to the relation in Figure 2a. For the H$_\alpha$-line 0.75 Å $\leq \Delta \lambda_D \leq 1.30 \, \text{Å}$ with the $\Delta \lambda_D = 1.07 \, \text{Å}$. Having the range of the change for $\Delta \lambda_D$(H$_\alpha$) and $\xi$(KCaII), we evaluated the temperature in the cold corona region using the relations shown in Figure 2b. The temperature was found to change from $5 \times 10^5$ K to $1.3 \times 10^5$ K. The line-of-sight velocities in the CCE-bulk were from 20 km s$^{-1}$ to $150 \, \text{km s}^{-1}$. In the H$_\alpha$-line the $\xi = 100 \, \text{km s}^{-1}$ and $\xi = 135 \, \text{km s}^{-1}$ were more probable, and in the K CaII line the $\xi = 45 \, \text{km s}^{-1}$ did. However, the CaII value might be underestimated because of the instrumental limitation.

We conclude that the investigated cold coronal region was dynamic and not homogeneous by its temperature and velocities. The dimension of the CCE was determined to be of $3.5' \times 4'$. The observation from the Earth are confirmed with the space investigations. The SUMER Spectrometer on SOHO has been used to observe the lines of the hydrogen Lyman series [7]. The line profiles were obtained near the limb from about $(+10)''$ to $70''$. The temperature ranged between $1 \times 10^5$ K to $2 \times 10^5$ K. The line broadening appears to be very large for the thermal contribution. With an assumed turbulent speed of $30 \, \text{km s}^{-1}$ [8] the $T$ has been calculated to be $1.2 \times 10^5$ K. Comparing our results with the results in [7] we can conclude that they agree sufficiently well. The cold corona is characterized by the temperatures which are one-two orders lower than the “usual" corona in quiet regions, but by its turbulent and line-of-sight velocities it is likely to be more dynamic than the quiet corona.


**ПОШУКИ ТА ДОСЛІДЖЕННЯ ХОЛОДНОЇ ЄМІСІЇ В СОНЯЧНИЙ КОРОНІ 11 СЕРПНЯ 1999 РОКУ**

Г. Якубаева, О. Смирнова, А. Делоне, А. Горяков, Г. Порфір'єва
Астрономічний інститут Штейнберга, Москва, 119889, Росія

Виявлено холодну коронну емісію під час інтерферометричних спостережень сонячного затемнення. Використано слабкі емісійні лінії H$_\alpha$, 6563 Å і K CaII 3933 Å та коронну лінію Fe XIX 5303 Å. Холодна ділянка була неоднорідною за своїми характеристиками. Визначено температуру й швидкість рухів у ній.