On Eclipse Polarimetry of the Inner White Light Corona

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Significantly reduced total solar eclipse sky brightness, low-scattered light instrumentation, and the use of a special algorithm for data reduction of allow us to carry out high precision linear polarization degree and direction determination with a realized accuracy of 1% and 1-2˚ respectively. Such an experiment was made during the total solar eclipse on August 11, 1999. The 2-D distributions of polarization degree and direction for the corona continuum radiation in the range 570÷-800 *nm* reveal different scale structures. Interpretation in terms of tangential (to the solar limb) velocities results in the detection of 30000 *km/sec* electron streams in the inner corona. These are not directly recorded either by current space or ground-based instruments in this optical spectral range.

Introduction

The term "white light corona" implies a corona observed in the visible and near infra red continuum. Emission of the white light corona consists of the *K* (electron) and *F* (dust) components. The *K*-corona emission dominates at distances <1.5 $R_\odot$ (from the center of the solar disk) and is caused by Thomson scattering of the photosphere radiation by free coronal electrons. It is highly *linearly polarized* [1]. Polarization measurements give information about radiation mechanisms, physical conditions, 3-D structure, as well as magnetic fields [2]. Reviews of linear polarization research of the white light corona are presented in numerous publications. However, the question about the existence of *abnormal polarization* (i.e. different from the *van de Hulst model*) is still open. The actual accuracy of former eclipse photographic polarization measurements does not exceed 6÷8 % for polarization degree (*P*) and 8-10° for orientation of the polarization plane (*a*). Below the polarization plane is defined as the *plane of oscillations of the magnetic vector*, coinciding with radial direction in the *van de Hulst model*.

An opportunity to detect tangential to the solar limb electron velocities was indicated in 1973 by Molodensky [3]. Scattering of the photosphere photons by *moving electrons* results in a rotation of the polarization plane due to aberration of light in the coordinate system moving with electrons. Deviations of the polarization plane from the radial direction indicate moving electrons. For a sub-relativistic approximation (velocities <30000 *km/sec*) this deviation is given by $\delta = V_t/c$, where V_t is the velocity component tangential to the limb, and *c* is the velocity of the light. *An actual accuracy* of 1° in polarization direction determination is required to detect, in optical spectral range, high speed electrons [4] which are often "seen" by radio methods.

Factors preventing high precision polarimetry were discussed in our former publications. Significantly reduced totality sky brightness (10^{-8} -10^{-10} of the solar disk brightness), low-scattered light instruments, the analysis of "statistical" data with a special algorithm of data reduction, results in an accuracy of 1% for polarization degree and 1-2° for polarization direction [5].

Instrumentation

A portable coronagraph-polarimeter (*D* = 55 *mm*, F_e = 339 *mm*) for eclipse observations in the upper solar atmosphere was developed and manufactured at Sternberg State Astronomical Institute of Lomonosov Moscow State University [6]. Unlike former eclipse instruments, a rotating polarizer is placed in the plane of the Lyot stop, and this is synchronized with a motion–picture professional 35-mm camera. The light beam of each "image point" of the object under study passes through the same surface of the linear polarizer. The diameter of the light beam at the polarizer does not exceed 10 *mm*. Such an optical lay-out results in significant reduction of errors caused by nonhomogeneity of the polarizer transparency which is placed in front of focal plane. This reduces degradation of the polarizer performance due to averaging over an extended surface when a polarizer is placed before the primary lens. Actual angular resolution equals 7-10''. One rotation of the polarizer corresponds to 24 frames. Period of polarizer rotation can be adjusted according to sensitivity of films. A prototype was tested during the total solar eclipse of 03 November 1994 in Brazil. Adjustment in the plane of Lyot stop was improved for the eclipse of August 11, 1999, in Bulgaria. A special algorithm was developed for data reduction based on Stokes vector presentation, the use of 24 polarization images corresponding to 24 orientations of the polarizer, and IDL software was developed to enable us to deduce *I*, *U*, *Q* Stokes parameters [5].

Observations and data reduction

Polarizer rotation with period of 5 *sec* and frame timing at 5 *frames/sec* was used for observations in Shabla (Bulgaria) during the total solar eclipse of August 11, 1999: λ=28°35.5 λ' , φ = 43°32', duration of totality was about 2.5 *minutes*. The *PION-500* spectrozonal, negative perforated, 35-mm aerial film manufactured by FOMOS factory (Russia) was used as a detector. Two layers of the film sensitive in 570÷690 and 670÷800 *nm* spectral intervals allow us to record the corona continuum and "cold" Hα-emission. Neutral density filters were used for absolute (solar disk) and relative (wedge) calibrations. The films were later digitized by a *Perkin-Elmer 1010 GM microdensitometer* of the Korea Astronomy Observatory: slit [0.01x0.01] *mm²* corresponds to [6''x6'']. Densities corresponding to the linear part of the characteristic curve were selected for further analysis. This restricted the observed range <1.5$R_\odot$. Digitizing, photometry, reduction, and preliminary results on orientation of polarization plane were given in [7].

Discussion

Comparative analysis of the 2-D distributions of the white light corona structure, linear polarization degree (*P*) and direction (*α* - deviation of polarization plane from the radial direction) is discussed below for the spectral interval of 570÷800 *nm*, angular resolution ~10″, distances <1.5 R⊙, an accuracy of 1% in *P*, and 2° for *α* (10000 *km*/sec in terms of velocity). Fig.1 shows the structure of the corona derived by A.O. Yuferev from the similar aperture images obtained by N.L. Kroussanova using the same film and at the same observational site in the corona color experiment.

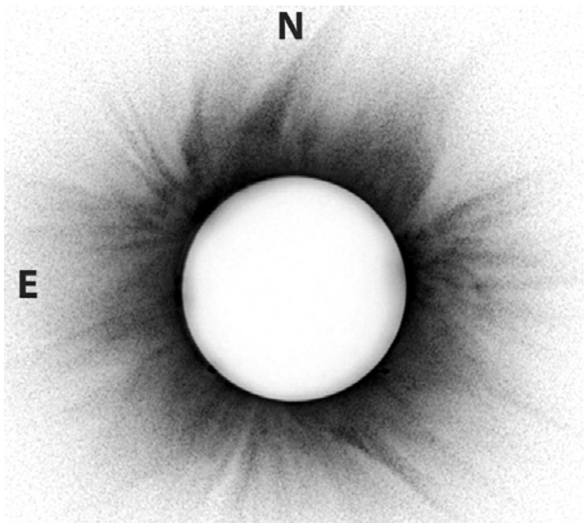

Fig.1. The August 11, 1999 white light corona structure.

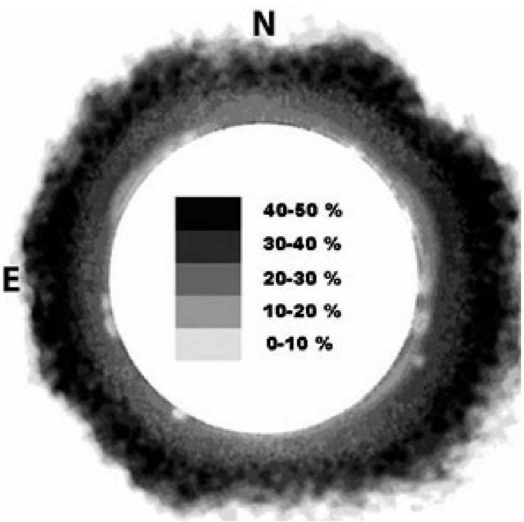

Fig.2. August 11, 1999. The 2-D distribution of polarization degree.

A quasi-symmetrical shape, typical for the maximum phase of the solar activity cycle is seen: large near radial helmet streamers above the SE, SW, and NW limb; curved streamers deviating from the radial direction above the NE and near the S limb; tiny quasi-radial rays within the active coronal region in NE and W sectors; numerous "small" bright features in the NE sector, and different types of Hα - prominences.

The 2-D distribution of *P* is shown in Fig. 2. A scale from 0÷50 % is given in the Moon's image location. Polarization analysis of Hα-prominences seen around the limb as areas with *P* <10% was presented before [8]. A very structural pattern not fitting *the van de Hulst model* in the range <1.15 R⊙ (polarization < 20 % for almost all position angles) are noted. Input of Hα-emission seems to be crucial in the inner most corona. A peak *P* of 50 % is found at 1.4÷1.5 R⊙.

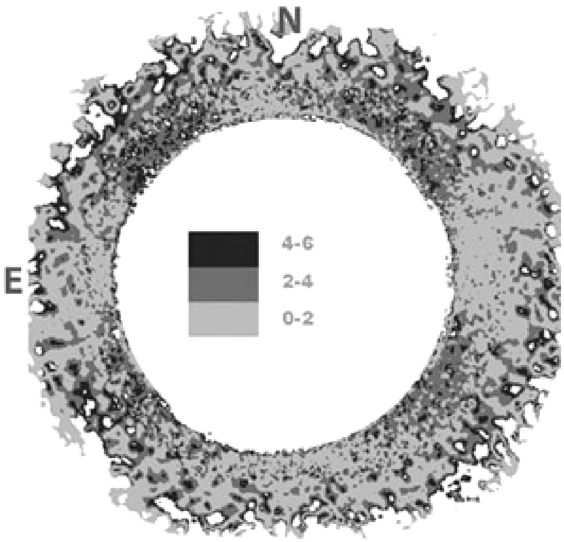

Fig.3. August 11, 1999. The 2-D distribution of polarization direction.

The 2- distribution of polarization direction (*α*) is shown in Fig.3 for the angle interval of 0÷6° in steps of 2°. "Small-scale" 30″ features, with deviations of 4÷6° (V_t of 20000÷30000 *km/sec*), are imposed on homogeneous large-scale structure of 0÷2° (V_t < 10000 *km/sec*) corresponding to the *van de Hulst model*. In particular, features at a height of about 100000 *km* in the active corona region above the NE-limb evidently trace curved coronal streams up to 1.5 R⊙. Deviations of 2÷4° (V_t of 10000÷20000 *km/sec*) are seen above the NE, SE, SW and NW-limb at the base of large-scale helmet streamers.

Conclusions

High precision polarimetry seems to be a powerful tool to search for tangential velocities in the inner corona. Low-scattered light optics, high performance polarizers, filters cutting Hα-emission and special algorithm for "data reduction" are required.

Acknowledgments

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