White light corona at different phases of the solar cycle

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Accepted: 12 October 2011

Abstract. White light corona observations during 3 total solar eclipses (1999, 2006 and 2009) at different phases of the solar cycle, and comparative analysis of the results are presented in this work.
Photos are made with objectives with different focus and exposure. Structures of the coronas are determined from composite images. Solar corona flattening is determined and its dependence from the solar cycle phase is investigated.
The connection of coronal structures with the long streamers is also studied.

Keywords: White light corona, total solar eclipse, phase of the solar activity cycle

Introduction

Total solar eclipses are still regarded as a unique possibility to observe the inner solar corona in details from the ground. They give an invaluable information about heating, structure and dynamics of the corona, and temperature distribution of quasi-stable coronal structures (active regions, coronal holes, bright points etc.). Comparisons with the information from space-based coronographs can reveal the mechanisms of energy release and energy balance in fast processes (flares, coronal eruptions, etc.) and the mechanisms of solar wind generation and acceleration.

The structure of the corona is determined largely by the three-dimensional extension of the emerged magnetic fields into the solar outer atmosphere. Consequently, the basic characteristics of the corona are controlled by the magnetic dynamo and its solar cycle variations. The minimum corona is much fainter and weaker than the maximum corona because of the absence of large active regions.

The observations of the July 22, 2009 total solar (TSE) eclipse were conducted near the town of TianHuangPing, China, close to the central line of the eclipse, by the Bulgarian – Russian team in the frames of the CORONA project of joint scientific research.

Co-ordinates of the site – near the upper reservoir of the Pumped Storage Power Station - are as follows: φ = 30°28′14.2″ N, λ = 119°35′29.0″ E, Alt. = 909m.

The Tianhuangping Power Station is the biggest of its type in Asia. It is located in Anji County in Zhejiang, about 175km from Shanghai and lies in a green bamboo forest regarded as one of the main bamboo production bases in China. The area is registered as "Green Resource" by the UN. The upper reservoir is a huge artificial lake on the top of the mountain. Shanghai Observatory, which belongs to Chinese Academy of Science, built an observing station on Tianhuangping. The station has two observatories, one for public education and the other for professional research. The international code for the station is D32.

The observations of the March 29, 2006 TSE were conducted near the town of Manavgat, Turkey (φ = 36°45′27.59″ N, λ = 31°27′14.11″ E, Alt. = 2m) [1]. The observations of the August 11, 1999 TSE were conducted around the town of General Toshevo, Bulgaria (φ = 43°41.7′ N, λ = 28°11.5′ E). Our team was located near the village of Ravnets. The weather was clear and we succeeded in obtaining relatively good photographs.

Experiments

Solar corona photographs in white light during the 1999 and 2006 TSE were obtained by a large-aperture cameras (200/1000mm and telescope 150/2250mm Meniskas - Cassegrain), and telescopes-refractors (63/840mm). Black and white professional photographic films Kodak T-MAX 200 Pro with unique structure were used. They ensure extraordinary sharpness of the image and high quality of the densitometric processing and printing. The films have been developed at equal physico-chemical conditions. During the 2009 TSE, the white-light corona photographs were obtained with 250/2000 mm objectives using high resolution digital cameras. Photographs were taken with different exposures, from 1/2000 sec to 5 sec, and show the variety of details in the coronal structure, caused by the heterogeneity of the solar magnetic field.

Results and Preliminary Analysis

Since Structural peculiarities of the corona are well visible on the negatives of the photographic films. "Helmet" type streamers and system of polar streamers are the basic details of the solar corona from the TSE on August 11, 1999 [2]. Fig. 1 shows the solar corona photograph in white light made during the 1999 TSE by a great light power camera (200/1000 mm) – with 2 sec exposure and the black and white pencil drawing of the solar corona during the total phase of the August 11, 1999 TSE of Zlatna Mychaylova.

During the 2006 TSE, all the basic coronal structures such as polar streamers, dome-shaped structures and "helmet" type structures, are evident from the composite image of 16 negatives taken with exposures from 1/2000 sec to 5 sec in white light (Fig. 2) [3].

Polar streamers are well developed in northern and southern hemisphere. Prominences originating and developed at middle heliographic latitudes (25° – 45°) are well outlined at the bottom of some large dome-shaped structures. Axis of symmetry of the "helmet" type streamers is tilted towards the solar equator. The deviations from a radial direction in western hemisphere (21°) are greater than that in eastern one (8°).

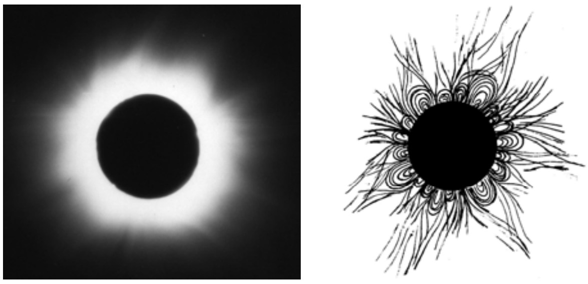

Fig.1. The solar corona photograph in white light made during the 1999 TSE by a great light power camera (200/1000 mm) - with 2 sec exposure. Black and white pencil drawing of the solar corona during the total phase of the August 11, 1999 TSE, by Zlatna Mychaylova.

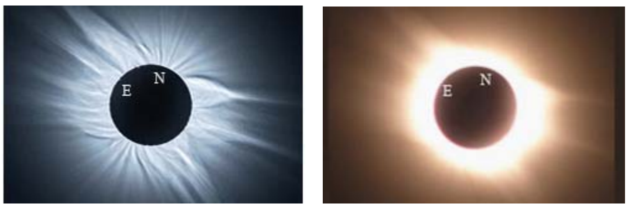

Fig.2. White light corona during the 2006 TSE. Polar streamers, dome-haped and ''helmet''-type structures are evident from the composite image composed of 16 negatives taken with exposures from 1/2000 to 5 s in white light with the help of telescope refractor 63/840 mm. Solar corona in white light (200/1000 mm reflecting objective).

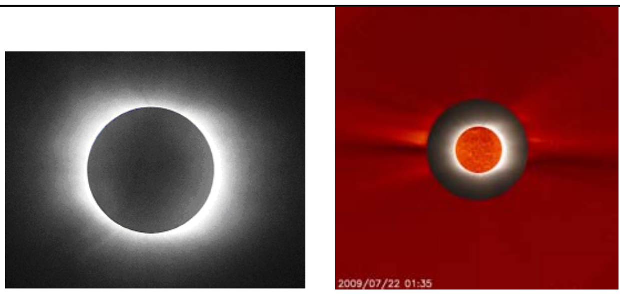

Fig.3. White light solar corona during the July 22, 2009 TSE, China, photogtaphed with a 250 mm objective (left). A solar eclipse photo (gray and white) from the Williams College Expedition to Tianhuangping, China (July 22, 2009) was superimposed on an image of the Sun's outer corona taken by the Large Angle Spectrometric Coronagraph (LASCO) and shown in red false color (right).

White-light corona during the 2009 TSE was investigated by observations with Ø=250 mm objective and Macsutov - Cassegrain telescope with focal length of 2000 mm. White light corona is photographed with a Canon 450D EOS with a Ø=250mm objective. The diaphragm f/d is 7.5 and the film sensitivity is ISO 200.

The exposition times vary from 1sec to 0.004 sec for the different parts of the corona. Forty eight images are obtained. Before and after the total phase are measured the dark current and the flat field. A solar eclipse photo (gray and white) from the Williams College Expedition to Tianhuangping, China (July 22, 2009) was superimposed on an image of the Sun's outer corona taken by the Large Angle Spectrometric Coronagraph (LASCO) and shown in red false color (right). It is shown for comparison (Fig. 3).

The solar corona flattening ε is the first quantitative parameter introduced for analyses of the global structure of the solar corona. It increases monotonically from the limb to some distance r, which varies from eclipse to eclipse within the range of ~1.4 $R_{\odot}$ to ~2.2 $R_{\odot}$ and it is sensitive to existence of coronal streamers at large heliographic latitudes. This ellipticity coefficient show that corona is very round at solar maximum, when streamers emerge from so many latitudes, and it is much more elliptical at solar minimum, when only a few streamers are visible at the equator. This way, the Luddendorf flattening coefficient shows the cycle of solar activity [4], [5], [2].

For determining of the flattening ε the formula of Ludendorf [6] has been applied

$$\varepsilon = \frac{d_0 + d_1 + d_2}{D_0 + D_1 + D_2} - 1 ,$$

where d_0 is the equatorial equidensity diameter, d_1 and d_2 are the diameters placed at angles of ± 22.5° in relation to d_0 ; D_0 is the diameter of equidensities passing through the solar poles and D_1 and D_2 are the diameters tilted to D_0 at angles of ± 22.5°. The flattening ε, which characterizes the solar corona type, is calculated at a distance of 2 $R_{\odot}$ from the solar disk centre – a way to remove the effect of the F-corona [7].

The flattening for the 1999 TSE is ε = 0.19 and this value corresponds to a intermediate (before the maximum) type of solar corona. The phase of the solar activity cycle can be calculated using the formula of [8]:

$$\Phi = \frac{T - T_{\min}}{\left| T_{\max} - T_{\min} \right|} ,$$

where T is the moment of the total solar eclipse, Tmin and Tmax are the nearest minimum and maximum of the corresponding solar cycles. The phase is calculated by linear interpolation between the closest maximum (Φ=1) and closest minimum (Φ=0). The sign + or – is assigned according to the rising and falling branch of the solar cycle, respectively. We have obtained a phase Φ = 0.60 for the 1999 TSE.

As for the 2006 TSE, the Luddendorf flattening coefficient is ε = 0.098 and this value corresponds to an intermediate (before the minimum) type of solar corona. We have obtained a phase Φ= -0.20. The solar corona flattening coefficient ε as a function of the solar cycle phase Φ is depicted on a diagram obtained by [5] who uses data for 51 solar eclipses. We have put our values for ε and Φ in the diagram (white stars, Fig. 4).

For the 2009 TSE ε = 0.091 and the phase Φ = 0.40. This illustrates that the corona is after-minimum type.

Fig. 4 shows that values of this analysis are in agreement with the general values by [5]. Only the value for the 2006 TSE is lower than all the others. We suppose that the reason is that the eclipse is at the long falling branch before reaching the deep minimum of the 23rd solar cycle.

The extent of the corona is very different from equator to limb because of the many dipole aspects of the solar magnetic field. Usually, coronal streamers are equatorial and the limb is graced by coronal plumes. Since all these features are magnetically governed, the shape of the corona varies greatly over the 11-year cycle of the solar activity. White light corona during the 2006 and 2009 TSE is asymmetric in contrast to solar corona observed during the August 11, 1999 TSE.

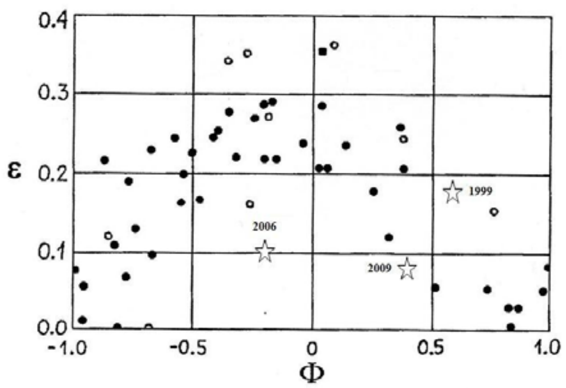

Fig.4. The solar corona flattening ε as a function of the solar cycle phase Φ for three total solar eclipses are shown as white stars. Other plots are results by Gulyaev (1997).

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