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REVIEW ARTICLE

White light coronal structures and flattening during six total solar eclipses

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Abstract Solar corona is very important part of the solar atmosphere, which is not available every time and it is very difficult to observe it. From solar corona we can get more information about outer sun layers. Large-scale structure of the solar corona can be studied during total solar eclipses.

The structure, shape and brightness of the solar corona significantly change from eclipse to eclipse. They depend on activity of the sun. At maximum solar activity, the corona is very bright and uniform around the solar limb. There are a lot of bright coronal streamers and other active regions on it. During minimum of solar activity the solar corona stretches at the equator and become elliptical.

Flattening index is the first quantitative parameter introduced for analyses of the global structure of the solar corona. It varies with respect to the phase of the solar activity and sunspot number. In this paper we study the solar corona during the 1990, 1999, 2006, 2008, 2009 and 2012 total solar eclipses. We obtain flattening coefficients for all the six eclipses by using a new computer program. Our results are in a good agreement with published results.

Contents

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1. Introduction

The total eclipse of the sun is truly a remarkable event not only because of the fact that the beautiful corona, prominences and all other associated phenomena are rendered visible, due to the hiding by the moon of the disk of the sun or the photosphere as it is called, but mainly because it enables astronomers to study these parts of the sun which are always invisible during bright sunshine, Madwar (1952).

The white-light corona, the outermost part of the atmosphere of the sun, has been observed photographically during the total eclipse of the sun since 1860 Pasachoff et al. (2007).

During the total solar eclipse, when the moon occults the sun for a few minutes we can observe the outer atmospheric layers of the sun, the chromosphere and the corona. The shape of the corona extends to several solar radii depending on the phase of sunspot cycle Marzouk (2013).

Markova et al. (1999) found that the structure of the corona is created by both the global and local magnetic fields. Structure and shape of the white-light corona during both total eclipses in 1997 and 1998 were of minimum type.

Rusin (2000) tried to express the shape and structure of the white light corona according to its brightness with three parameters: ellipticity, structure, and integral brightness. All these parameters are closely connected. They vary with the activity cycle phase, and reflect mainly the magnetic field of the sun, which is generated below the photosphere, in the convection zone, erupts through the photosphere and permeates the surface.

In this work we compare the defined features of the solar corona during six total solar eclipses (1990, 1999, 2006, 2008, 2009 and 2012) at different phases of the solar activity cycle. Also, we have calculated the flattening index of the solar corona during all eclipses by the help of a new computer program (Matlab R2012 language program).

2. Data used

The observations of total solar eclipses (TSEs) in 1990, 1999, 2006, 2008, 2009 and 2012 were conducted at different sites of the world.

July 20, 1990 – near the town of Kem, Karelia, Russia (Lat. = 64°57′N, Long. = 34°36′E, Alt. = 165 m).

August 11, 1999 - around the town of General Toshevo, Bulgaria (Lat. = 43°41.7′N, Long. = 28°11.5′E, Alt. = 200 m).

March 29, 2006 – near the west border of Egypt, Salloum city, Egypt (Lat. = 31°34′3.23″N, Long. = 25°7′ 9.35′E, Alt. = 202 m).

August 1, 2008 – near the town of Bijsk, Altay, Russia (Lat. = 51°58′N, Long. = 84°57″E, Alt. = 360 m).

July 22, 2009 - near the upper reservoir of the TianHuangPing Pumped Storage Power Station, China (Lat. = 30°28′14.2″N, Long. = 119°35′29.0″E, Alt. = 909 m), near the Shanghai Observatory, which belongs to the Chinese Academy of Science.

The November 14, 2012 TSE was observed in the region of Mount Molloy, 150 km from Palm Cove, Cairns, Queensland, Australia (Lat. = 16°29′45.6″ S, Long. = 144°58′17.4″E, Alt. = 342 m).

3. Flattening of the solar corona

Flattening of the solar corona (Ludendorf coefficient) ε characterizes the shape of the isophotes of the white-light solar corona. It increases monotonically from the limb to some distance r, which varies from eclipse to eclipse within the range of $\sim 1.4 R_{\odot}$ to $\sim 2.2 R_{\odot}$ and it is sensitive to the existence of coronal streamers at large heliographic latitudes. The rise of ε can be approximated with a linear function $\varepsilon = a + b\ (r-1)$, where r is the mean equatorial radius of an isophote. The value $a + b$, equal to ε at $r = 2$, is just the classical parameter of Ludendorff. Flattening can be defined as:

$$\varepsilon = (r_e/r_p) - 1 \quad (1)$$

where r_e and r_p are the equatorial and polar distances of the isophotes from the center of the solar disk respectively.

Ludendorff (1928) made first quantitative analysis of the shape of the solar corona. He analyzed isophotes of coronal images and defined the averaged flattening of the solar corona by the formula:

$$\varepsilon = [(\mathrm{I} + \mathrm{II} + \mathrm{III})/(\mathrm{IV} + \mathrm{V} + \mathrm{VI})] - 1 \quad (2)$$

where I, II, II, . . . , VI designate six diameters of one and the same isophote separated at angles of $\pm 22.5°$.

4. Results and discussion

The most fundamental coronal characteristics (polar plumes, dome-shaped structures and helmet type streamers) have been observed on the images of the studied six total solar eclipses (1990, 1999, 2006, 2008, 2009 and 2012).

The total solar eclipses in 1990 and 1999 were during the maximum of the 22nd and 23rd solar activity cycles, respectively. These coronas show many streamers located at all azimuths around the occulted disk of the Sun (Fig. 1a and b).

The Total Solar Eclipse in 2006 occurred near the following minimum of the 23rd solar activity cycle. We can see in Fig. 1c stalks of helmet extend to 3 solar radii. The existence of different zones in the observed white light corona is clearly noticed.

According to the consensus reached by The Solar Cycle 24th Prediction Panel on May 8, 2009: the 24th solar cycle begins in December 2008. The 2008 total solar eclipse is on the minimum of solar cycle. Structures are also outlined on the composite image of the white-light corona - shape of the corona and number of streamers are different. The deviations of dome-shaped structures in western hemisphere are smaller than those in eastern one (see Fig. 1d).

The 2009 total solar eclipse is also in minimum but on the beginning of ascending branch of the 24th solar cycle. The quiet Sun corona shows larger helmet type streamers concen-

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