OBSERVATIONS OF THE ECLIPSED CORONA. THE ORIGIN OF THE "MINIMUM" AND "MAXIMUM" CORONA

V.G. Eselevich, V.M. Grigoryev, V.I.Skomorovsky,
R.T.Salakhutdinov

ISTP SD RAS, P.O.B. 4026, Irkutsk, 664033, Russia
phone: +7 395 2 46 26 91, fax: +7 395 2 46 25 57
e-mail: esel@iszf.irk.ru

ABSTRACT

Observational results on the corona at the time of solar eclipses July 11, 1991 and March 9,1997 are given. The analysis of it's and some another observations of eclipses which did another authors was shown: 1) A limiting case of a "maximum" corona (for example, the eclipse of February 16, 1980) is observed in the events where the planes of portions of the streamer belt (or chain), which follows a meridian, lie near the picture plane on both limbs, E and W simultaneously. 2) A limiting case of a "minimum" corona occurs when the plane of the streamer belt (or chain) is perpendicular to the picture of projection on both limbs simultaneously. The angle Θ_0 of inclination of the streamer to the equator is determined by the latitude Θ at which the portion of the belt under consideration is located. In the phase of minimum $\Theta_0 \approx 0°$(the eclipse of March 9, 1997), near maximum activity can reach $\pm(50°-70°)$ (the eclipse of July 11, 1991). Prediction of the coronal structure for February 26, 1998 and observation results are discussed.

1. INTRODUCTION

Numerous observations of the corona at the time of solar eclipses during the last decade gave birth to the notion of the "minimum" and "maximum" corona. The "minimum" corona is exemplified by an essentially asymmetric (about the solar center) brightness distribution around the solar disk. In a limiting case, it is representable as brightness contours elongated at a certain angle to the equatorial line on both sides of the solar disk along the radius. At distances $R > 3R_0$ they show up as streamers of enhanced brightness. In a limiting case the "maximum" corona is characterized by a somewhat uniform arrangement of these streamers around the Sun [Ref. 1]. Furthermore, while the "maximum" corona is observed only near the phase of maximum solar activity, the "minimum" corona can be observed in any phase of declining solar activity [Ref. 1,2].

The objective of this paper is to analyze the origin of two limiting cases of the corona: "minimum" and "maximum", based on our observational data on total solar eclipses, as well as the method and results reported in [Ref. 3].

2. METHOD AND RESULTS OF OBSERVATION OF THE SOLAR ECLIPSES OF JULY 11, 1991, AND MARCH 9, 1997

<u>The eclipse of July 11, 1991, La Paz (Mexico).</u> Sun's altitude 82°, ambient temperature +35°C. Eclipse duration 6 min 15 s. Two devices were used to photograph the solar corona.

1. Catadioptric lens MTO-1000 (Maksutov system) with the photographic camera and the coelostat mirror. The diameter of the objective lens is 100 mm. The working section of the objective lens was increased to accommodate the photographic camera "Kiev" with 60 mm photographic film, and the equivalent focal length became 1300 mm. Exposure and film rewinding on the photographic camera were done manually. A radial filter was manufactured for the device. A coating of chromium and quartz mixture was applied to the glass substrate to serve as an absorbing layer. The mixture acted to reduce the absorption factor of absorbing coating. The filter's maximum density near the limb was 3.1 (done with a classical prediction). The R-filter was placed behind the blind of the cine camera shutter in the film channel at the distance of 0.1-0.3 mm from photoemulsion. The central zone of the filter, equal approximately to R_0, had no absorbing coating. It was used to match the image position in the telescope and the guider from a star, and to permit guiding and photometric calibrations of photoemulsion from the solar center. During the eclipse, nine pictures with 3-15s exposures were taken. Fig. 1 shows a photographic print from frame No. 2.

2. The other instrument was a telescope (F=500mm, D=70mm) on equatorial mounting. The polarization angular R-filter was placed ahead of the objective lens. That was our first attempt to use, for such a filter, Iceland spar crystals, whose transmission between the two polarizers in a direction close to the crystallographic axis depends on the angle of incidence ϕ (between the telescope axis and the direction toward the chosen area of the corona). The transmission of the two-stage filter obeys the law $I=I_0\sin^4(\phi)$ and is independent of the beam's position at the entrance pupil. This filter was used to obtain the corona image in the red region of spectrum up to distances $1.5R_0$. Unfortunately, the transmission of the filter was found to be slightly too small.

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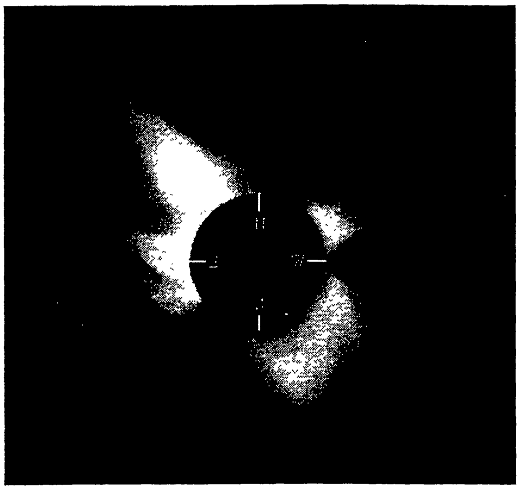

Figure 1. The corona as photographed during the solar eclipse of July 11,1991.

The eclipse of March 9, 1997, Yerofei Pavlovich, Chita Region, Russia. Sun's altitude 23°, eclipse duration 2 min 37s, air temperature -25° C.

A telescope with the Petzwahl four-element lens was constructed; it comprised two achromatic components 120 mm and 105 mm in diameter. One of the lenses was made aspheric to minimize the spheric aberration. The equivalent focal length of the telescope was 1200 mm. The theoretical resolution for the field ±2° was 5 arcsec. At the time of observations, the telescope tube was supported in horizontal position by two stands. The tracking system, the coelostat mirror, was installed on a separate foundation. For the corona 1997 observation, several radial filters were constructed (for the instruments used by other expedition participants) with a density distribution in accordance with a classical prediction. Unlike the former filter, the 1997 filter featured a higher density, and starting from the limb it had a steeper slope and longer wings extending beyond $4R_0$. When constructing the filter, a decrease in reflection from the metal layer was detected (when applying an interference coating of absorbing material on the metal-glass interface). The filter must be facing the objective lens with its glass substrate, to which, initially, an "antireflecting" coating of tungsten and, subsequently, an absorbing coating of iron film was given using the method of electron-beam evaporation. Coatings, protected by a sapphire film, withstood 100% humidity. The lowest reflection factor was 5%, and in the region 400-800 mm the reflection factor at the ends of the range did not exceed 12%. The filter was installed in the telescope's focal plane at 3 mm from the cine film. The camera AFA-39 was employed. The film width was 80 mm. Automatic film advance was succeed. An electromagnetic curtain shutter was placed in front of the objective lens.

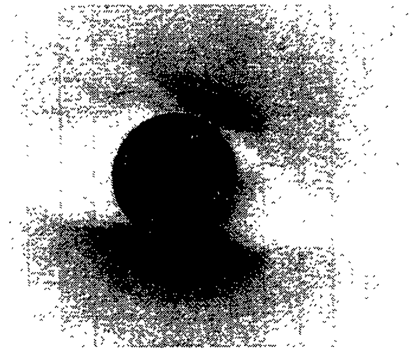

Figure 2. The corona as photographed during the solar eclipse of March 9, 1997.

Despite a very low ambient air temperature, all the planned series of ten pictures with exposures from 1 to 10 seconds were taken automatically in accordance with the specified program. In Fig.2, one can see the corona image up to $4.3R_0$, as well as the fine structure (arcades). The extent of the corona image was limited because of a large amount of scattered light in the Earth's atmosphere. The predicted distribution of the filter did not match a change in brightness of the corona in streamers. The difference in brightness was corrected when printing the pictures by a suitable choice of exposures for different parts of the images. There was a total mismatch between the filter's density variation and the corona brightness in the meridional direction. Because of guiding errors (the observer was looking at the sky rather than the guider, being amazed by the eclipse of the luminary!), the center of the solar image did not coincide with that of the filter. Therefore, less dense parts (within the limb) of the filter were displaced into the polar crown on several frames. And this made it possible to obtain the polar regions without overexposures.

All the pictures that were taken are now digitized on a microphotometer. Photographs of a part of the sky, obtained with the radial filter, are used for photometric referencing of different pictures.

3. QUALITATIVE CHARACTERISTICS OF STREAMER BELTS. THE ORIGIN OF THE "MINIMUM" AND "MAXIMUM" CORONA

In the qualitative analysis of streamer belts, in addition to the above events in Fig.1 and 2, events are also used, for which it was possible to find in publications the necessary, sufficiently sharp K-corona pictures up to distances over $3\text{-}4R_o$ from the solar center.

The event of June 1 - 2, 1988, from [Ref. 4]. We choose this event to demonstrate our method of analysis. Schematic positions of the streamers from June 1 (04:23) and June 2 (19:59) on the W limb based on a K-corona photograph from

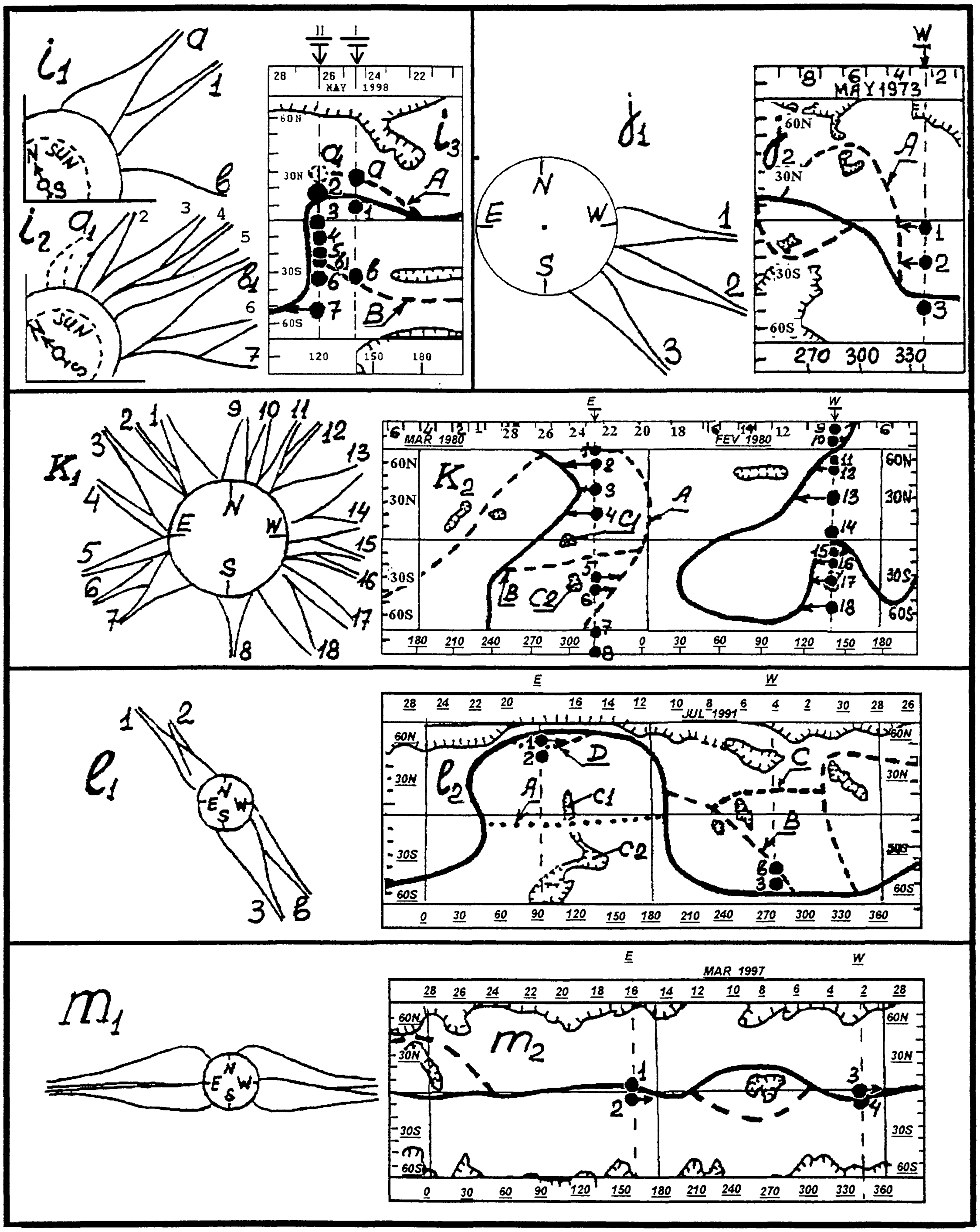

Figure 3. Schematic representations of streamers sketched from white-light corona pictures from Fig. 1 and Fig. 2, and from [Ref. 4,5] - (i_1, j_2, k_1, l_1), and their respective positions (dark circles) on synoptic maps - (i_3, j_2, k_2, l_2): (i_1) -June 1, 1988 (04:23UT); (i_2) - June 2, 1988 (19:59 UT); (i_3) - portion of CR 1802; (j_1) - June 10, 1973 (09:43UT); (j_2) - portion of R 1602; (k_1) - February 16, 1980; (k_2) - CR 1691; (l_1) - June 11, 1991; (l_2) -CR 1844; (m_1) - March 9,1977; (m_2) - CR 1920. The arrows indicate belts, to which streamers belong. The NL position is shown by a solid heavy curve; streamer chains - dashed heavy curve; coronal holes - thin solid curves with shading into the hole region; individual streamers - dark circles.

Hundhausen [1994] are shown in Fig.3i_1 and Fig.3i_2. Positions of streamers in these events on the synoptic chart are shown in Fig.3i, along vertical dashed lines I and II, respectively. The comparison of Fig.3i_1 and Fig.3i_3 reveals: streamer "a" belongs to the conjectured streamer chain - "A", streamer 1 belongs to the belt with NL, and streamer "b" refers to the streamer chain - "B". Next, we compare Fig.3i_2 with Fig.3i_3: here the situation has changed drastically because the belt with NL lies nearly in the limb plane. (Streamer "a_1" of belt "A" has disappeared because it decayed under the action of a CME [Ref. 4]. Streamer "b_1" belongs to belt "B", and another six streamers are arranged along the belt with NL: 2, 3, 4, 5, 6, and 7. Such a change in the picture suggests two important factors:

1. A minimum angular deviation from the limb plane, after which the streamer becomes invisible, is $\Phi \sim 26°$ (two days). (On a photograph of an intermediate instant of time of June 1, 1988 (14:37) from [Ref. 4], the brightest parts of streamers 2-7 near the Sun are discernible.) About the same value of the quantity Φ for Mauna Loa observations is obtained in calculations from [Ref. 4].
2. At distances $R > 3R_0$ from the solar center, the streamer belt constitutes a sequence of rays along the belt. Each ray has the cross-section with a typical latitudinal size "D_f", and Longitudinal size "D_t". The distance between the rays $L > D_f, D_t$.

The event of June 10, 1973 (09:43)), near minimum solar activity, from the eclipse photograph of [Ref. 5]. Schematic positions of the streamers of June 10 (09:43) on the W limb, based on a K-corona photograph from [Ref. 5], is shown in Figure 3j_1. (a CME was on the E-limb at that time). Positions of these streamers on the synoptic chart are shown in Fig. 3j_2 along the vertical dashed line W. From the comparison of Fig. 3j_1 and Fig.3j_2 it follows that: streamers "1" and"2" belong to the conjectured streamer chain - "A", and streamer "3" belongs to the belt with NL. The value of $L \sim 20° - 25°$.

The event of February 16,1980, near maximum solar activity from the eclipse photograph of [Ref. 6, 7]. Schematic positions of the streamers of February 16, 1980, on the E limb and W limb are shown in Fig.3k_1. Positions of the E and W limb streamers on the synoptic chart are shown in Fig.3k_2, along the vertical dashed lines E and W, respectively. From the comparison of Figure 3k_1 and Figure 3k_2 it follows that: on the E limb streamers "1","5", "6", "7" and "8" belong to the conjectured streamer belt without NL - "A", and streamers "2", "3" and "4" belong to the chain. The absence of streamers from chain "B", between streamers "4" and "5" may be due to the possibility that at the time of corona photography coronal holes C1 and C2 constituted a common coronal hole and hence streamer chain "B" separating them was absent. The value of $L \sim 10° - 30°$. On the W limb the ten streamers all belong to the belt with NL. $L \sim 10° - 30°$.

The event of July 11, 1991, near maximum solar activity. The eclipse photograph on Fig.1. Schematic positions of the streamer rays of July 11, 1991, on the E-limb and W-limb, based on a K-corona photograph, is shown in Fig. 3l_1. Positions of the E and W limb streamers on the synoptic chart are shown in Fig. 3l_2 along vertical dashed lines E and W, respectively. From the comparison of Fig. 3l_1 and Fig. 3l_2 it follows that: on the E-limb streamers "1" and "2" belong to the belt with the NL line. In this case the observed belt appears to pass somewhat below (dash-dotted line D) the calculated NL. The absence of the streamer from chain - "A" may be attributed to the fact that at the time of corona photography coronal holes C1 and C2 constituted a common coronal hole. Therefore, belt "A" was absent. The value of $L \sim 20°$. On the W limb streamer "B" belonged to the streamer chain "B", and streamer "3" belonged to the belt with NL. No streamers from the possible chain - "C" were seen on the eclipse photograph.

Event of March 9, 1997, near the minimum of solar activity (photograph in Fig.2). Streamer positions on March 9, 1997, on the E-limb and on the W-limb, deduced from the K-corona photograph in Fig.2, are shown schematically in Fig.3m_1. E- and W-limb positions of streamers on the synoptic map are shown in Fig.3m_2, respectively, along vertical dashed lines E and W. From the comparison of Fig. 3m_1 and 3m_2 it follows that: On the E-limb streamers "1" and "2", and on the W-limb streamers "3" and "4" belong to the belt with NL.

4. PREDICTING THE CORONAL STRUCTURE FOR FEBRUARY 26, 1998, AND OBSERVATION RESULTS

The above-stated knowledge of the coronal structure may be useful in predictions. Predicting the coronal structure is considered to mean forecasting the positions of the corona's most extended and brightest elements, or streamers. At this point, we resort to brightness data on the white-light corona acquired by the LASCO C2 instrument aboard the SOHO spacecraft (received via INTERNET). The working coverage of C2 measurements is $R=(1.5-6.0)R_o$. Daily images in the FITs format spanning the time interval from December 24, 1997 through February 15, 1998, were used. Brightness of these images was scanned azimuthally at $R=4.5\ R_o$ (at E and W limbs). The scans were used to deduce the position of the maximum brightness distribution relative to the equator for each day. The resulting positions were then plotted on a synoptic map. The dates on the synoptic map for the events under consideration were determined by adding seven days to the observation time of the event on E-limb and by subtracting seven days from the observation time of the event on W-limb.

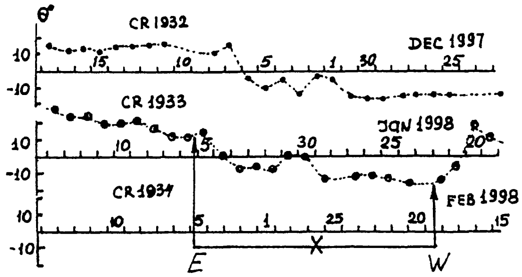

Figure 4. Position of brightness maxima of the white-light corona of the streamer belt at $R = 4.5R_o$ obtained from brightness profiles on W-limb (full circles), and on E-limb (open circles) for rotations 1932 and 1933. X - eclipse day, for which the coronal structure is predicted.

The resulting positions of streamer belts for Carrington rotations 1932 and 1933 are shown in Fig. 4. The figure shows that a reconfiguration of the belt from rotation to rotation proceeds relatively slowly. This fact may be useful in predicting the coronal structure during the February 26 eclipse of the next rotation 1934. The day of eclipse in Fig. 4 is shown by a cross, and the limb positions for that day are marked by the arrows with the corresponding letters E and W. Assuming that the structure of the belt in rotations 1933 and 1934 is about the same, from Fig. 4 we have the following prediction:

a) On the E-limb at the latitude about N12±5 degrees – a bright streamer up to distances larger than (4-5) R_o and an increased brightness at the latitudes N5÷S10 within the distances (1-2)R_o (due to the influence of the February 3-5 portion of streamer belt rotation 1933).

b) On the W-limb at the latitude about S20±10 degrees - a bright streamer up to distances larger than (4-5) R_o and an increased brightness at the latitudes S10÷N10 within the distance (1-2) R_o (due to the influence of the January 20-22 portion of streamer belt rotation 1934).

By comparing this prediction with the photograph of the corona taken during the February 26, 1998 eclipse in Fig. 5, we obtain a good agreement.

5. CONCLUSIONS

1. A limiting case of a "maximum" corona (for example, the eclipse of February 16, 1980) is observed in the events where the planes of portions of the streamer belt (or chain), which follows a meridian, lie near the picture plane on both limbs, E and W simultaneously.
2. A limiting case of a "minimum" corona occurs when the plane of the streamer belt (or chain) is perpendicular to the picture plane both limbs simultaneously. The angle Θ_0 of inclination of the streamer to the equator is determined by the latitude Θ, at which the portion of the belt under consideration is located. In the phase of minimum $\Theta_0 \sim 0°$ (the eclipse of March 9, 1997), near maximum activity can reach ±(50° - 70°) (the eclipse of July 11, 1991).

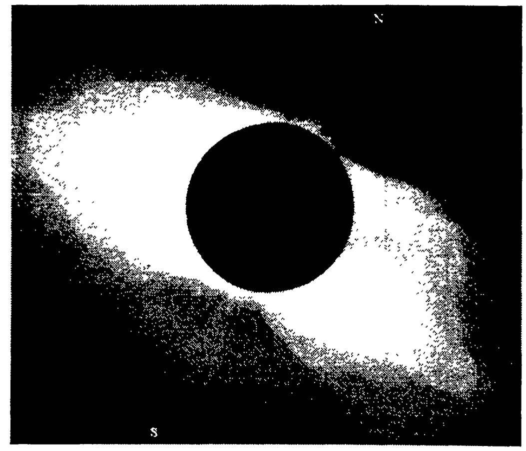

Figure 5. Photograph of the corona taken during the February 26, 1998 total eclipse.

6. ACKNOWLEGEMENTS

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