The eclipse corona: reality and possible research during the 1999 eclipse

V. Rušin and M. Rybanský

Astronomical Institute of the Slovak Academy of Sciences
059 60 Tatranská Lomnica, The Slovak Republic

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Abstract. Solar eclipses provide a unique opportunity to observe the solar corona and to solve many open questions in solar coronal physics, e.g., heating of the corona, small-scale structures, dust particles, formation and distribution of coronal structures around the solar surface with respect to the photospheric activity centers, polarization, dust vaporization near the Sun, formation and spatial orientation of solar wind streamers, etc. The forthcoming 1999 eclipse will pass across many countries in Europe, the Middle East and Asia. This event will provide a good opportunity to perform observations of the corona with 'bigger' equipment to obtain high-resolution. We propose to focus scientific experiments on the following targets:

The white-light and emission corona: exact photometry of the corona with telescopes of focal length 1 - 3 m; in detail, photometry around the poles and/or above active regions with a minimum focal length of 5 m; photoelectric detection of oscillations; co-ordinated observations with 'smaller' telescopes, of 1 m focal length, along the umbral path (dynamics and large-scale structure), polarization in emission corona, etc.

Spectral observations: detection of short-term oscillations (less than 0.1 s) in individual spectral emission coronal lines or in the white-light corona; polarization in emission coronal lines (the Hanle effect - direction of coronal magnetic field lines); spectral observations with small-scale resolution: colour of the solar corona, large-scale resolution: profiles of emission lines; depth of absorption lines (F-corona), etc.

Moreover, high-precision timing of eclipse contacts can help us to obtain more accurate parameters of the Moon's orbit around the Earth and to measure the diameter of the Sun. Comets, if any, should be studied in the close vicinity of the Sun.

We are of the opinion that the most important problems in solar coronal research during the 1999 eclipse will be supported by coordinated ground-based and satellite observations.

Key words: The Sun – corona – eclipse – observational program

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1. Introduction

The solar corona (see Plate II) is hot and diluted plasma above the solar photosphere which extends very far from the Sun. However, its light is very faint relative to the visible disk of the Sun (of 10^{-6}, decreasing to 10^{-9}) within one solar diameter from the visible disk. The sky brightness exceeds that of the corona by 3 to 5 orders of magnitude so that the corona is normally invisible. Solar eclipses are rare occasions offering an opportunity to observe all parts of the solar corona (E-corona: emission corona, caused by actual emission of radiation by highly-ionized species in the corona; K-corona: 'continuum' corona, caused by scattering of photospheric light on coronal electrons; F-corona, 'Fraunhofer' corona, caused by scattering of photospheric light on dust particles around the Sun, and T-corona, 'thermal' corona caused by thermal (mostly infrared) emission of interplanetary dust (the same nature as the dust for the *F-corona*). Since the discovery of the corona as a part of the Sun in 1860 by Secchi and Warren de la Rue, much theoretical and observational work has been done on understanding the physics of the solar corona.

Nevertheless, there are many problems not fully solved yet, e.g.

- the heating of the corona,
- support of the coronal mass,
- co-existence of the hot corona and cool prominences,
- faint structure of the solar corona,
- acceleration of particles from the corona into the solar wind,
- distribution of coronal structures above active regions, their development over the solar activity cycle,
- neutral matter in the corona and existence of the *T-corona*, etc.

It is generally accepted that basic processes in the inner corona are responsible for the state of the corona in its upper part and in the solar wind. However, this inner part of the solar corona can not be observed from the space. Details of solar coronal research may be found in many monographs, e.g., Waldmeier (1957), Shklovskij (1962), Billings (1966), Rušin and Rybanskỳ (1990), Golub and Pasachoff (1997) and references therein.

The main objectives of this paper are (1) to show problems in the solar corona physics and propose some experiments to solve them, and (2) to discuss other open questions that may be studied over the 1999 total solar eclipse.

2. The 1999 eclipse

The 11 August 1999 total solar eclipse will occur shortly before the maximum of cycle 23 (supposed to be in 2000 – 2001) and the path of the Moon's shadow (see Figure 1) will pass over 18 countries from Europe to Asia. This is a good opportunity to observe the solar corona from 'domestic' observational sites for European astronomers, using equipment with high spatial and temporal reso-

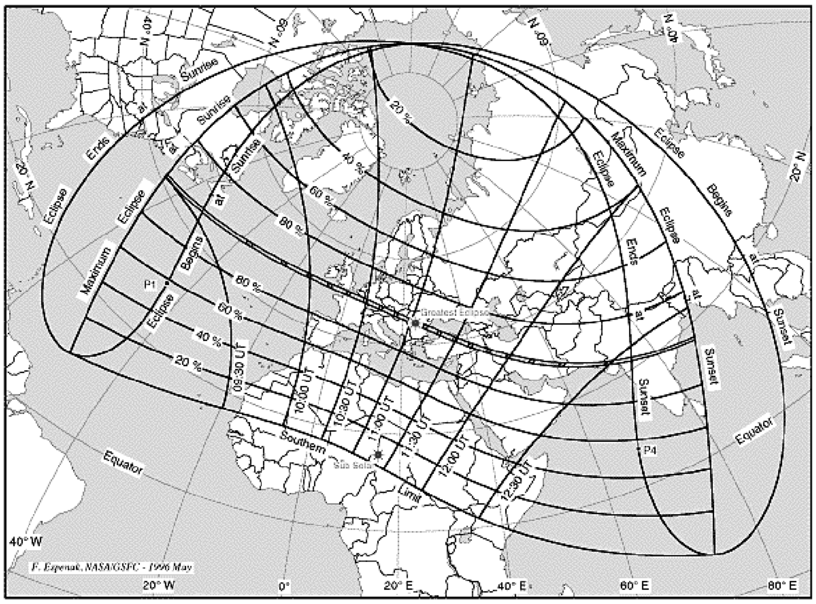

Figure 1. The path of the shadow for August 11, 1999 eclipse (Espenak and Anderson, 1997).

lution. The eclipse path will cover, e.g., Bucharest where large telescopes are installed (Stavinschi, this isue). The weather conditions (Espenak and Anderson, 1997) should be also very favourable, expecially in Turkey and Iran.

3. Solar corona problems (puzzles)

3.1. The heating and support of the solar corona

The questions of how the corona is heated to its temperature of a million degrees and how the corona and its structures are maintained remain the major unresolved questions of solar physics. It is generally accepted, e.g., Narain and Ulmschneider (1990), Ulrich (1996) that different types of hydrodynamic and magnetic waves are responsible for heating of the corona. The primary source of this energy is believed to be the convection zone below the solar surface, and "magnetic field acts as a 'waveguide' for MHD disturbances generated in the convection zone: Alfvén waves or other MHD disturbances propagate outward along the field lines that protrude through the solar surface and dissipate their energy in the corona" (Golub and Pasachoff, 1997). We note that some oscillations, e.g. 300 s, 40 s, 7.5 s or shorter, have already been detected both in the emission and white-light corona, e.g., Koutchmy, Žugžda and Locans (1983), Pasachoff and Landman (1984), Rušin and Minarovjech (1994) and Singh et al.

(1997). One may suppose that these detected oscillations could be closely connected with the above mentioned 'heating' waves. On the other hand, theories

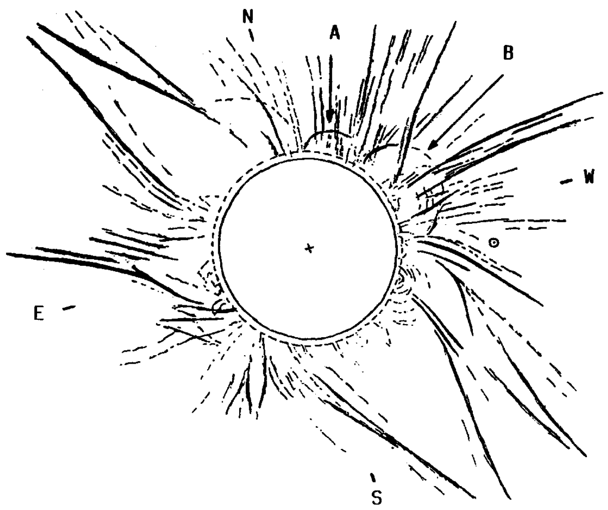

Figure 2. Structure of the white-light corona on July 11, 1991.

for the above mentioned waves also require the existence of short-term oscillations, e. g. 1 s or shorter. Such experiments have been performed, e.g., Pasachoff and Landman (1984). Preliminary results have shown that existence of waves below 1 s could exist. Such experiments should be continued in the future, especially during the forthcoming eclipse. The other reason to continue these experiments is to investigate the existence of very faint coronal structure as we will discuss later on, and also the transport of particles from the solar surface into the corona.

The solar wind is an outflow of particles from the corona into the heliosphere. The mass of the corona could 'evaporate' during 30 minutes into the heliosphere through the solar wind. However, the corona continuously exists, even when their mass (brightness) changes between the minimum and maximum in the ratio of 1:2.5 (Rušin and Rybanský, 1985). This means that the mass of the corona must be continuously supplied from the solar surface. There are, however, several open questions: Is this process running continuously or as a 'cascade'? Where is the place for this process? Is this done through spicules, prominences, nano-flares? Is this process done anywhere on the solar surface or between the supergranules, granules, or elsewhere? It seems that an input of surface mass into the corona and heating could be closely connected and, probably, these processes can occur as 'shock waves' or 'electric discharge' or 'magnetic reconnection'. Anyway, the input of the surface mass into the solar corona could be detected with a high temporal and spatial resolution.

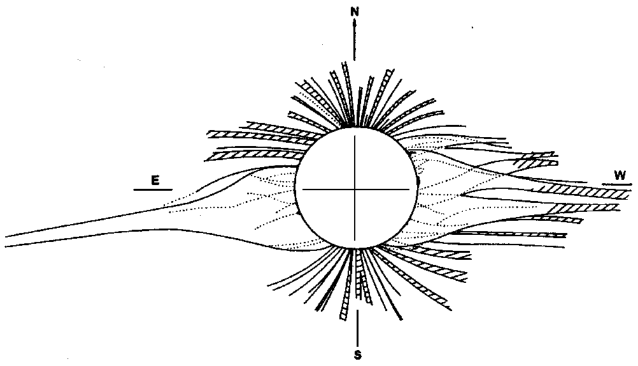

Figure 3. Structure of the white-light corona on October 24, 1995.

3.2. Faint structure of the solar corona

It has been known for a very long time that the corona has different type of structures (polar rays, helmet streamers, dark cavities above prominences, loops, threads). Improved ground-based observations during eclipses and also from space in the different parts of the electromagnetic spectrum have shown that the corona is much more structured than was supposed before the 1970s: bright coronal points, coronal holes, loops connecting close (far ?) active regions in the photosphere. Some of these structures are shown in Figures 2 and 3. However, completely new insights into the faint coronal structures occurred after the 1991 eclipse, observed with a-CCD camera at the prime focus of the CFHT at Hawai (Koutchmy, 1992). Short-lived (of 200 s) phenomena at sub-arcsecond size (0.4 arcsec) were detected in the eclipse corona for the first time. They are called 'plasmoids.'

Detailed analysis of Hawai pictures, carried out by November and Koutchmy (1996), has shown another type of faint coronal structures (Koutchmy, this issue, c.f. Fig. 4): sub-arcsecond radially oriented rays and loops, located above the prominence. Both phenomena confirmed the idea, which originated in the 1980s, that the solar corona is a highly dynamic and structured object. The latest studies of the faint coronal structure and dynamics, discussed above, are another call to observe the corona with higher spatial and temporal resolution.

3.3. Density, temperature, shape and structure of the corona

The solar corona during eclipses is mostly observed in white-light, and, in our opinion, it will continue to be so, in the future. Based on such observations, the following properties of the corona can be studied: physical conditions (density and temperatures – derived from the intensity of the K-corona, see Fig. 4),

structure (depends on the distribution of magnetic fields both the global and local, on the solar surface, see Figs. 2 and 3), and shape of the corona expressed

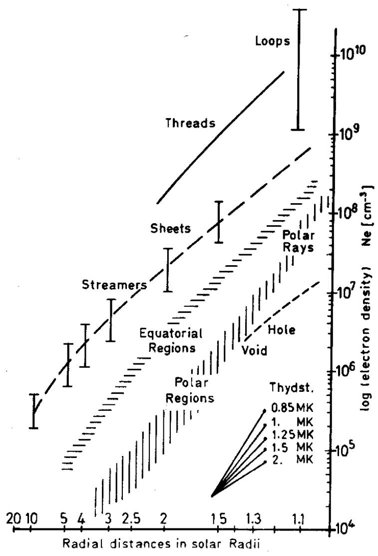

Figure 4. Radial variations of the electron density in different structures in the corona as derived from eclipse photometry (Koutchmy, 1992).

through *flattening index* (see Fig. 5) derived for 2 $R_\odot$ from individual isophotes as defined by (Ludendorf, 1928).

In order to express brightness of the corona, the integral brightness (or total flux) was introduced in the range of 1.03 - 6.0 $R_\odot$ (see Figure 6). The above mentioned properties of the corona change with a solar cycle activity as can be seen from Figures 2 and 3. The structure and shape are frequently used to describe the eclipsed corona, and together with the integral brightness are used to study long-term variability of the corona with a solar cycle. Rušin and Rybanský (1985) found a relation between the flattening index $a + b$ and the integral brightness. We would like to note that properties of the solar wind, which interacts with the ionosphere of the Earth, are given by the temperature, density and structure (magnetic fields) in the lower corona (below 2 $R_\odot$). Recently, the elliptical shape of the corona has been questioned by Sýkora et al. (1998), based on observations of the 1991 eclipse. Nevertheless, the ellipticity reflects the corona state in the cycle in the first approximation very well. Exceptions could occur due to the position of the magnetic dipole of the Sun relative to the observer on the day of the eclipse.

We use a term *the white-light corona*. It consists of the light of the K-corona (electrons) and F-corona (dust particles). To separate them, two methods can be used: (1) polarized observations, and (2) spectral observations of the photospheric and coronal spectrum (method of comparison of the depth of Fraunhofer lines). The first method allows one to separate the above mentioned components

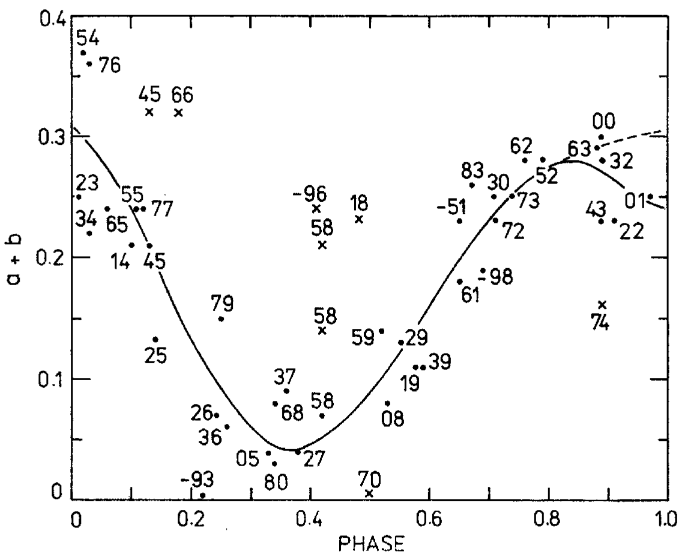

Figure 5. Flattening index $a + b$ versus solar cycle.

from simpler observations (minimum of three positions through a polarized filter), the second one is much more precise, however, but rarely used. Advantages and disadvantages of these methods are discussed, e.g., by Golub and Pasachoff (1997), in detail. Briefly, some earlier results, based on observations with low resolution and using some assumptions, e.g., totally polarized K-corona and unpolarized F-corona, stable brightness of the F-corona over solar cycle, and accepted for the whole corona, did not hold up when observations were made with higher resolution. To better understand the solar corona and its individual structures, new observations should be made, with both higher temporal and spatial resolutions.

3.4. Neutral matter in the corona, F-corona

As we noted in the *Introduction*, scattering of photospheric light on free electrons is the basic mechanism for the light of the corona. It is assumed that corona consists mainly from free electrons and particularly from ions.

Grotrian (1934) theoretically solved what emissions are coming from the corona due to the scattering on interplanetary dust particles. Recent observations, e.g., Dorotovič et al. (1998) showed that the solar corona also contains neutral matter. The question of how the corona contains neutral matter or dust particles remains an unresolved puzzle of solar physics. The existence of matter in the neutral state in the corona could significantly change the electric and thermic conductivity of the corona. The presence of the neutral matter in the corona can be indicated via colour of the corona. To solve both these problems,

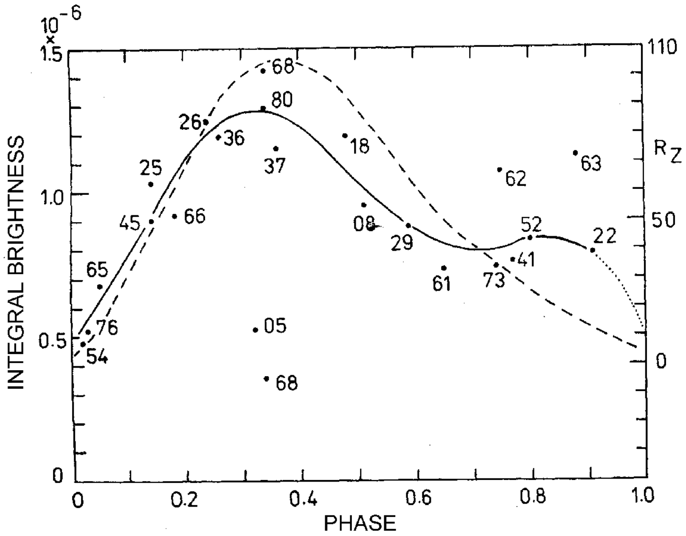

Figure 6. The integral brightness versus solar cycle.

very precise (less than 0.1%) spectroscopic (visual and IR) and polarimetric observations are needed. Spectroscopic observations can be done through a narrow pass-band filter or with a spectrograph. Using filter observations only in one spectral emission line, polarization in the emission can be studied. So, the Hanle efect enables us to derive direction of fieldlines in the corona. Direct measurement of magnetic fields in the corona, the most important parameter, is impossible due to great width of emission lines (of 0.1 nm) and the weakness of the field. Polarimetric observations in green (530.3 nm) and red (637.4 nm) coronal lines were made by many authors, e.g., Mogilevsky et al. (1960), Hyder et al. (1968 and references therein), who obtained contradictory results (see Fig. 7). While the observed polarization in the green corona (maximum 42.9%;) mostly agrees with theoretical calculations (Figure 8) made by Charvin (1965), the polarization in the red corona at the 1954 eclipse (Mogilevsky et al., 1960) was extremely high: 82%.

Other measurements in the red corona did not show such high polarization, and the obtained values of polarization were close to the theoretical predictions (zero value). Charvin (1965) and Hyder (1965) have found that the red coronal line cannot be polarized naturally if its identification is correct. Recent results of polarimetric observations in the green emission coronal line (Badalyan and Sýkora, 1997), made through a passband narrow filter, have shown that the degree of polarization in this line is contradictory to its intensity, however, in agreement with theoretical predictions. Nevertheless, polarization of emission coronal lines is still open, especially in the yellow lines 569.4 nm and 544.6 nm

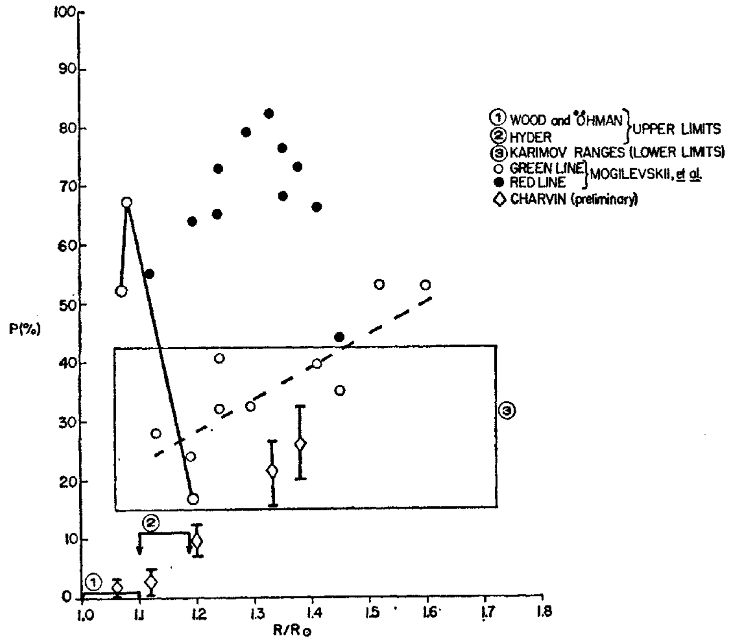

Figure 7. Observations of polarization in the green and red coronal lines. Solid line connects polar observations in the green line, and dashed line is the average for equatorial observations (Hyder et al., 1968).

(to the best of our knowledge, nobody measured it), and each a such experiment would be highly welcome. As was stressed by Hyder et al. (1968), *'accurate measurements of polarization in the various coronal lines provide another dimension in the fixing of their identifications and in estimating the abundances of the parent ions'.* This open question is very closely connected with the identification of emission coronal lines in the visible part of the spectrum (Mouradian, 1997).

Results from spectrographic observations low resolution, but with high precision of the photometry (0.1% or better), enable us to derive the colour of the corona. Difference between photospheric and coronal colour can be used as a measure for relative abundance of neutral matter in the corona, as was recently discussed by Dorotovič et al. (1998). On the other hand, a spectrograph with an intermediate resolution can be used to separate K- and F-coronal light according to the depth of absorption lines. The depression in the depth of the K-corona is usually used to derive the temperature of the K-corona. This method may be used only in regions of the corona with very strong lines. Thus, a classic method for determination of the temperature follows from hydrostatic balance (van de Hulst, 1950).

Large-scale spectrographic (slit) resolution may be used to find the profile of emission lines in the visual and near infrared range of the spectrum. As pointed

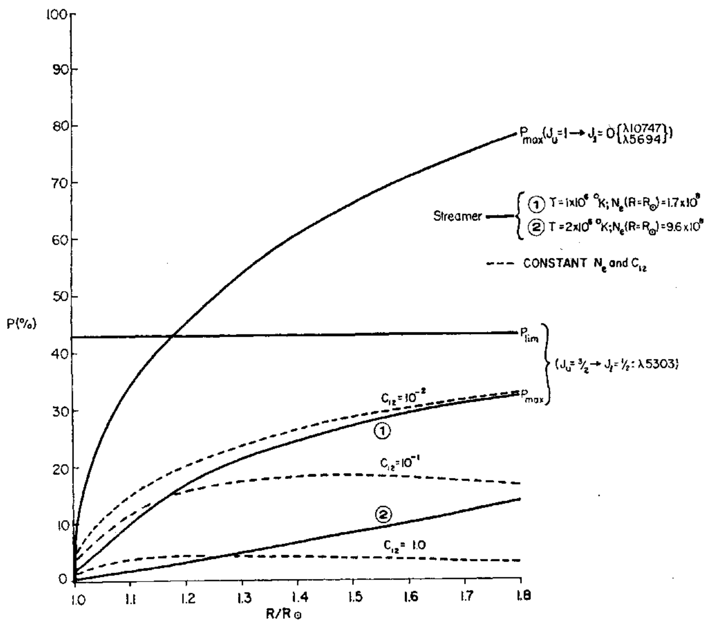

Figure 8. Theoretical results of Charvin. J_u is the J-value for the upper level of the transition, and J_l is for the lower level (Hyder et al., 1968.)

out by Mouradian (1997), there are 91 emission lines (between 300 – 3000 nm) in the corona, however, only 31 lines have been observed twice or more.

New infrared techniques allow us to observe the outer solar corona in the infrared solar spectrum to 20 micrometers. Such observations are important for 2 reasons, at least:

1/ Emission coronal lines Fe XIII (1074.7 and 1079.8 nm) together with the Fe XIII 338.8 nm provide a valuable electron-density diagnostic; the intrinsic polarization of the Fe XIII 1074.7 nm line may be used for measurements of coronal magnetic fields (only direction) at reduced sky brightness. The sky brightness decreases as a function of wavelength.

2/ Detection of excess (see Figure 9) at 4 $R_\odot$ at wavelengths 2.12 micrometers or less, could solve the problem of the 'local dust', probably connected with the sungrazing comets (MacQueen et al., 1994) or the existence of a vaporization zone which could permanently exist around the Sun. This excess is caused by absorption of the photospheric light and its re-emission in the infrared spectrum. This excess is very frequently called *T-corona, 'thermal corona'*. Details can be found in MacQueen (1968) and/or in Rabin et al. (1994).

Very recently, Gulyaev (this issue) based on his own observations proposed to introduce a new term in the corona: *S-corona* – 'sublimation corona'.

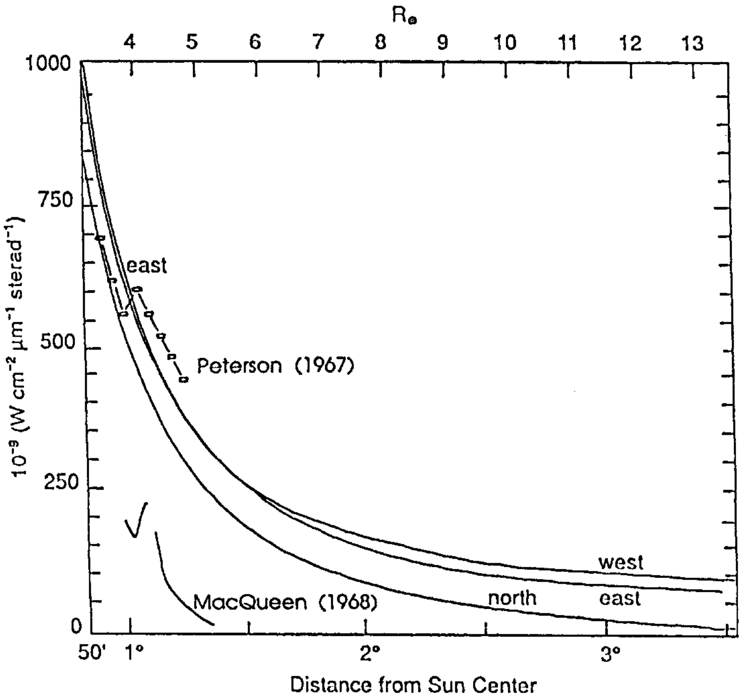

Figure 9. Radial scans of the near infrared coronal radiance observed on the east, west and north solar limbs at the 1991 eclipse, and equarorial scans by observers at the 1966 eclipse (MacQueen et al., 1994).

4. Astrometric observations (Contact timings)

Precise timings of apparent contact between the Moon and Sun can be used in two ways:

- to determine the precise orbit of the Moon around the Earth. This role can be made even outside of totality path.

- to derive the solar diameter (only in the path of totality) relative to the Moon at the time of eclipse. Observers are standing along the border at the northern and southern limits of umbral path. The shadow has strong limit, and depends on geographical location. Modest equipment, i.e., a small telescope, short wave radio, and portable camcoder may be used for such measurements. The precisional requirements of these observations (Espenak and Anderson, 1997) are around 0.5 s in time, $1''$ (of 30 meters) in latitude and longitude and 20 m in elevation. Such measurements are essential to an ongoing project to study changes in the solar diameter. The solar diameter is an important parameter for energy output from the Sun, and there is no doubt that total radiative energy from the Sun heats our Earth.

5. Conclusion

As we have tried to show, there are many open questions in solar physics to be studied during the 11 August 1999 eclipse. It is very difficult to say which experiment is better and more important, which unresolved problem is 'hotter'. We can only provide a recommendation, and the final solution has to be taken by individual persons or groups. We would like only to stress that each observation is important and our knowledge about the solar corona will be better, having more excellent observations with both higher temporal and space resolution.

The solar eclipse permits us to study other open questions, e.g., Einstein's theory (curvature of the light), comets in the vicinity of the Sun, flash spectrum of the chromosphere (especially weak lines and abundance of helium), physical conditions in the Earth atmosphere, influence of the eclipse for society, etc. All these questions are beyond the scope of our talk. Nevertheless, they can be done by anyone.

As regards our group from AI SAS at Tatranská Lomnica, we will observe the WLC with a 20 cm lens, 3 m focal length, fed by the light from a single mirror (a siderostat) in collaboration with Dr. A. Ozguc and his team from Kandilli Observatory and Dr. B. Livingston from NSO/Kitt Peak Observatory. This experiment will concentrate on the small-scale structure up to 2 $R_\odot$ and very precise photometry, and teams will have their observational site in Elazig. The above mentioned region in the corona cannot be observed with the SOHO coronagraph C2. Other experiments in the white-light, just under discussion, will probably be: the photometry and large-scale structures (several different smaller telescopes of 1 m, 0.5 m and/or 0.3 m, located in more places in the totality path), polarimetry of the WLC, and an experiment for the study of the colour of the solar corona (spectrometric and WLC polarization observations will be done in Hungary).

Many domestic, e.g., Belgium, Romania, Turkey, and international working groups (IAU, JOSO) have been established to coordinate the planned eclipse experiments with other ground-based and space programs at or around the eclipse period.

We would like to notify that chairpersons for the IAU eclipse working group are Prof. J. M. Pasachoff (jmp@williams.edu) and Dr. F. Clette (fred@oma.be) for the JOSO eclipse WG 7. These international working groups will try to coordinate observational program during the last 1999 total solar eclipse in the millenium. Many stimulating ideas for observation of the solar corona could be also found in the book *Solar Coronal Structures* (Rušin et al., 1994).

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Discussion

Comments (S. Koutchmy):
1) Several IR imaging experiments performed in 1991 did confirm that the so-called 'T-corona' rings (around the Sun near 4 $R_\odot$, etc.) do not show up. Additionally, the LASCO coronograph aboard SOHO performed imaging during more than 2,5 years without any evidence of such rings, even at a very low level of intensity modulation.
2) Fine polarimetric analysis of emission lines of the corona can more easily be performed using ground-based coronographs outside of eclipse. During total eclipses it is more efficient to try to measure emission lines at larger radial distance.
Question (P. Heinzel): *Concerning high spatial resolution observations, are there any plans to use larger telescopes along the totality band, e.g. in Bucharest?*
Answers:
S. Koutchmy: No real plans yet.
M. Stavinschi: I will answer your question in my talk. There are several instruments at Bucharest and Timisoara observatories.