Photometric and Spectrometric Investigations of the Solar Corona and Atmospheric Effects during the forthcoming March 29, 2006 Total Solar Eclipse

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A great part of the information about large-scale structure of the solar corona comes from solar observations during total solar eclipses. Space coronagraphs over-occult the Sun, omitting from view exactly the inner and coronal reasons well imaged at total solar eclipses. The total eclipse of the Sun on 2006 March 29, will be visible from within a narrow corridor, which transverse half the Earth. We foresee observations from the territory of Turkey. The aims of observations are: Photometric investigation of the White corona structure and polarization; Investigation of the structure of monochromatic emission corona in green (Fe XIV, λ=5303Å) and red (Fe X, λ=6374Å) line, Hα, and the thermal corona in the 2÷5 μm region of the Infrared spectrum; Tropospheric and stratospheric O_3 and NO_2 photochemistry study; Determining of the dynamics of basic microclimatic parameters of the 10 m ground atmospheric layer.

The following methods will be used: Taking of photograph of the corona (telescope-refractor 100/1000mm, spectrozonal photoemulsions, polarization and infrared barrier filters), registration of the investigated emissions (telescope-refractor 150/1600mm, high sensitive photo-emulsions, narrow band filters), Differential Optical Absorption Spectroscopy method, measuring of the microclimatic parameters with automatic meteorological station; processing and analysis of the photographs and data, seeking for wave structures in the O_3 and NO_2 concentration, comparison with other measurements during an eclipse.

The results we expect are: Determining of the Solar corona characteristics, finding of regularities in the O_3 and NO_2 behavior in conditions of reduced solar radiation, and clarifying the dynamical and photochemical processes in the stratosphere and climate of the ground atmosphere.

Introduction

A great part of the information about the large-scale structure of the solar corona comes from solar observations during total solar eclipses. Also, the transition of energy and matter from the photosphere through the chromosphere to the solar corona can be studied only during natural or artificial eclipses. The orbital heliospheric observatories gave the possibility of continuous investigation of the physical conditions of the solar corona and the processes acting there. Very faint structure features can be seen using image processing technique, though the space coronographs overoccult the sun, omitting from view exactly the inner and coronal reasons well imaged at total solar eclipses.

Solar eclipses have been also taken seriously into account by the Atmospheric and Environmental Sciences to study the response of the atmosphere during the interesting and particular circumstance in which solar light is partially or totally being blocked by the Moon. A total eclipse of Sun is about as close to a controlled experiment as an atmospheric research can hope for. Sunlight diminishes at a uniform and predictable rate, and near totality, the dark umbra of the Moon sweeps across the top of the atmosphere in a narrow predictable path. It is then possible to study how chemical and physical processes in the atmosphere take place owing to the absence of sunlight. Specifically, while a total eclipse is in progress typical optical, meteorological, environmental and other physical/chemical effects appear.

The eclipsed solar corona

At solar eclipses corona appears as a pearly white halo extending far from the Sin's limb. A brighter inner halo hugs the solar limb, and corona streamers extend far into the space.

The visible corona

Coronal continuum radiation at optical wavelengths is composed of two parts - K-corona (dominating near the Sun, at distances of about 2.3 $R_{\odot}$) and F-corona (Fraunhofer corona - evident farther out to a few solar radii). K-corona results from photospheric light scattered by electrons. As these free electrons are usually concentrated above the regions of strong magnetic field, comparatively bright coronal structures – streamers, loops and holes - are formed above such regions. Coronal holes mark areas where magnetic fields from the Sun continue outward into space and the coronal gas flow away from the Sun making the Solar wind.

Superimposed on the electron - scattering continuum is the F-corona spectrum, which comes from light scattering from dust particles, identical to those grains that pervade interplanetary space. The dust is concentrated in the plane of the ecliptic, for we see the outer extension of the F-corona as the zodiacal light. K- and F- corona form the so called white corona.

A great part of the contemporary information about the large-scale structure of the SC is obtained from photographs in a white light during total solar eclipses.

The condition that the intensity of the white light corona is in linear correlation with the free electrons' density makes possible direct photometric measurements of the coronal density during a total solar eclipse. Large scale distribution of the coronal electron concentration is obtained by photographic observations using linear polarizator. Series of photographs should be made with different exposure. After photometric processing, the obtained isophot maps are used for coronal flattening and large scale structure estimation.

Investigation of the physical conditions and small scale structures of the inner corona by measuring and analysis of the emission line intensities is of basic significance. A lot of bright emission lines are superimposed on the visible coronal continuum and form the so called E-corona. More than 100 coronal emission lines in a wide range of wavelengths - from $\lambda = 3300$ Å to $\lambda = 12200$ Å - were discovered during total solar eclipses. Coronal lines are emitted from highly ionized atoms of iron, nickel, and calcium. Three of them are particularly well known: the red line (FeX λ 6374 Å), green line (FeXIV λ 5303 Å) and yellow line (CaXV λ 5694 Å).

All the lines are stronger near the zone with sunspots. Coronal lines shining are connected with the sunspots and similarly those moves towards the equator with coming nearer to a period of maximal solar activity. Monochromatic corona is highly heterogeneous. Structures as streamers, loops, holes etc. can be observed. The ratio of green and red line intensity at a given point is used for determining the coronal temperature. The emission line intensity significantly changes with the solar activity cycle. It is greater during maximal solar activity

Thermal radiation of the heated dust in the infrared spectrum ($2 \div 5$ μm) is the T-corona. Resonance emissions of metal atoms and low-charged atoms occur while the dust sublimates. Large Doppler shifts could be associated with emissions due to fast moving sublimating gas. This new component of the solar corona radiation is named S-corona.

According to some arbitrary criteria SC is divided into three regions - inner, middle and outer. The inner SC extends to the upper boundary of the chromosphere - up to $\approx 1.3\ R_{\odot}$ and it is very bright. The middle one is placed in the region of $1.3\ R_{\odot} \div 2.3\ R_{\odot}$. In the outer SC - as far as $2.3\ R_{\odot}$- the F-corona radiation prevails.

Prominences (filaments) mark active regions of the Sun. They are streams of chromospheric gas occupying coronal regions tens of thousands of kilometers above the chromosphere. They are visible in white light at total solar eclipse and are best recorded in Hα or CaII lines.

Photographs of the solar corona made during total solar eclipses show that its structure depends on the heliographic latitude and longitude, from the distance to the solar limb and from the solar activity cycle phase. At times of sunspot maximum, the corona is very bright and uniform around the solar limb and bright coronal streamers and other condensations associated with active regions are much in evidence [1].

One of the most exciting problems for the last 50 years is: “Why the solar corona is so hot?” – the temperature of general coronal features is at least 1 000 000 K. A lot of information has been obtained in recent years from several high-resolution imaging instruments on spacecraft such as SOHO (Solar and Heliospheric Observatory), TRACE (Transition Region and Coronal Explorer), and Yohkoh. Magnetic field embraces whole the corona and its form is determined by the geometry of the local magnetic fields of the loops, arcs, coronal holes [2, 3]. It is known that some mechanism must exist whereby magnetic energy is converted into thermal energy. It is likely that the energy that heat the corona derives either from dissipation of magneto-hydro-dynamic (MHD) waves [4] or from numerous small scale magnetic reconnections giving rise to small flares, at the limit of detection by spacecraft instruments (“nanoflares”) [5 - 8]. According to [9] some recent works with SOHO data suggest that extreme UV brightenings seen in the quiet Sun network are so numerous that heating by such phenomena may be more than adequate to explain the heating of the quiet corona. Nevertheless, wave heating is likely to be significant, in particular in regions of open magnetic field where reconnection results in mass motions or particle acceleration rather than direct heating. At present, such processes could be investigated only from the Earth, during total solar eclipses or ground based coronographs, as only very high frequency (> 0.5Hz) waves maybe capable of significant heating of coronal loops. Such frequencies are higher than what is in principle possible to examine from spacecraft instruments because of telemetry rate limitations.

Atmospheric response and climatic changes

It is interesting to investigate the atmospheric response and climatic changes when the solar radiation income sharply diminishes during a total solar eclipse.

The stratospheric ozone as a natural shell for the Earth's biosphere is a subject of a special attention during the last decades.

Ground-base observing systems: Global Ozone Observing System (GO$_3$OS) of the World Meteorological Organization WMO, Network for Detection of the Stratospheric Changes (NDSC) etc. are organized for deep study of the ozone long-time trend, time and spatial (vertical and horizontal) variations.

The satellite instruments: Total Ozone Monitoring Spectrometer (TOMS) [10], Global Ozone Monitoring Experiment (GOME) [11], Solar Backscatter Ultraviolet Radiometer (SBUV) [12], etc. are pointed to discover the specific patterns of the global total ozone. The aircraft and balloon experiments give additional contribution to better understanding of the dynamical processes (vertical and horizontal transport) and the stratospheric ozone chemistry.

Specific characteristics have been found in the polar regions, at the mid latitudes and at the equatorial latitudes. Different models are established to explain the short- and long-time behavior of the ozone and the related minor and trace gases involved into its chemistry. A special attention is paid to nitrogen dioxide, which plays an important role in the ozone photochemistry.

The main diurnal variation of NO_2 is a result of N_2O_5 photolyses,

$$N_2O_5 + h\nu \rightarrow NO_2 + NO_3,$$

and naturally its concentration has Solar Zenith Angle (SZA) dependence, due to the diurnal variation of the solar irradiation.

Time scales of the chemical reactions are in order of few minutes in the low stratosphere and go faster in the upper stratosphere. NO_2, NO and O_3 are involved into the following reactions and the variation of the concentration of one of these gases creates some modification of the concentrations of the others:

$$NO_2 + h\nu \rightarrow NO + O, \qquad NO + ClO \rightarrow NO_2 + Cl,$$
$$NO + BrO \rightarrow NO_2 + Br, \qquad NO + HO_2 \rightarrow NO + OH,$$
$$NO + O_3 \rightarrow NO_2 + O_2$$

A part of these reactions are photosensitive, and we have to expect effects upon gaseous concentrations if the solar flux which arrives at the stratosphere is reduced due to natural phenomena as solar eclipses. These investigations give an opportunity to verify the existing knowledge in the field of stratospheric photochemistry of ozone and nitrogen dioxide [13 - 18]. For better understanding of the reason of their fluctuations, additional well coordinated measurements are need.

Atmospheric temperature and pressure rapidly change during total solar eclipses, which produce meteorological anomalies typical in this kind of phenomena [19]. Among them is the appearance of winds, which would eventually influence in a positive way - cleaning the air pollution if the eclipse is being observed from a contaminated area. That is why the basic climatic parameters have to be measured with high sensitive meteorological instruments: temperature (air and soil), relative humidity, pressure changes and speed of the wind in the 10 m air layer, including the terrain level. These observations could be compared with those already published elsewhere and with models.

Experience

Researchers of the STIL-BAS, Stara Zagora Department and the Yuri Gagarin Public Astronomical Observatory in Stara Zagora have a good experience in Total Solar eclipse observing. Some of them participated in expeditions for TSE observations in Kem, Russia, July 20 1990, Bologna and Mt Cimone, Italy, October 12 1996, and General Toshevo, Bulgaria, August 11 1999. We work together with researchers from the Sofia University, Astronomical Institute and National Institute of Meteorology and Hydrology; in cooperation with scientists from Russia - IZMIRAN, Romania – The Astronomical Institute, Turkey - Kandilli Observatory, and Georgia – the Abastumani Astrophysical Observatory. We also foresee collaboration with the Levedev Physical Institute, RAN, Russia.

Solar Eclipse Observations

A solar eclipse was first recorded 2000 B.C.

2159 to 1948 B.C. are legendary dates from China in the Shu Ching of the first recorded solar eclipse. In this myth, Chinese astronomers Hsi and Ho fail to prevent or predict or properly react to an eclipse and are ordered to be executed by an angry emperor.

1307 B.C. First recorded observation of the corona (or prominences?) during a solar eclipse - in China on oracle bones: “three flames ate up the Sun, and a great star was visible”.

Astrophysical observations of solar eclipses continue more than a century and a half. A lot of techniques and instruments connected with photography and spectral analysis application were used. Several basic observational programs with a concrete scientific aims and tasks and highly innovative observational equipment are usually prepared and realized during every solar eclipse [20]. They include:

1. Analysis of the global characteristics of the solar corona.
2. Analysis of the emission spectrum and small scale structures of the corona.
3. Registration and analysis of the coronal oscillations.
4. Registration and analysis of the regions of the solar wind acceleration.
5. Atmospheric and environmental study of the atmospheric response to diminished solar radiation - color and brightness of the sky, atmospheric temperature and pressure, physical and chemical effects.
6. Investigation of biological and other effects.

The March 29, 2006 Total Solar Eclipse

The total eclipse of the Sun, on March 29, 2006 will be visible from within a narrow corridor, which crosses half the Earth. The path of the Moon’s umbral shadow begins in Brazil and extends across the Atlantic Ocean, northern Africa, and central Asia, where it ends at sunset in western Mongolia. A partial eclipse will be seen within the much broader path of the lunar penumbral shadow, which includes the northern two thirds of Africa, Europe, and central Asia

We plan to observe the eclipse and conduct our experiments from Side, near Antalya, together with our colleagues from Kandilli Observatory, Istanbul, because it is one of the sunniest places in Turkey – the percent of possible sunshine is 60%. Full phase of the eclipse begins at 10:56 UT

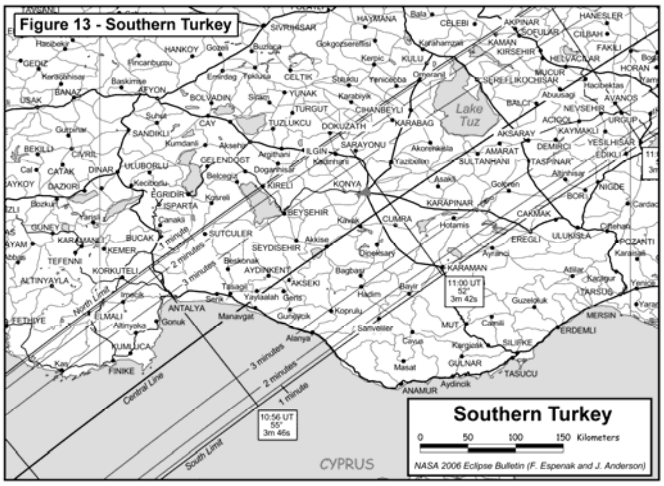

Fig.1. Path of the eclipse through Turkey

and its full duration will be 3 min 46 s, Fig. 1 [21].

Aims of the observational program

The aims of the investigations during the 2006 Total Solar Eclipse are:

1. Photometric investigation of the White corona structure and polarization.
2. Investigation of the structure of monochromatic emission corona in green (Fe XIV, λ=5303Å) and red (Fe X, λ=6374Å) line, Hα, and the thermal corona in the 2÷5 μm region of the Infrared spectrum.
3. Tropospheric and stratospheric O_3 and NO_2 photochemistry study.
4. Determining of the dynamics of basic microclimatic parameters of the 10 m ground atmospheric layer.

The data obtained will give the opportunity of continuing the research on different problems, comparing the results with those derived from previous ground based or satellite observations, and aircraft and balloon experiments.

Scientific methodology and observational approach

To make photography observations of the corona (telescope - refractor 100 / 1000 mm, spectrozonal photoemulsions (color positive film AGFA RSX-II, Kodak Ektachrome Professional Infrared EIR Film, black and white Kodak TMax P3200 film), polarization and IR barrier filters with a step of 2, 3, 4 and 5 μm).

Registration of the investigated emissions (telescope-refractor 150/1600mm, heliostat, high sensitive photo-emulsions, black and white Kodak TMax P3200 film, narrow band filters Hα - 6563 Å, FeXIV – 5303 Å, FeX – 6374 Å, Andover Corporation.

The slant column concentrations of O_3 and NO_2 are determined using the Differential Optical Absorption Spectroscopy method. The instruments, named GASCOD and used for stratospheric minor and trace gases study, have very narrow field of view of the input optics (Cassegrain type, f'=1500mm, d=300mm). This provides the best approximation of the atmospheric transfer equation model for the interpretation of the solar light radiation scattered at the zenith. Jobin-Yvon diffraction grating, 1200p/mm is incorporated inside the instruments. The spectral interval able for measuring is 300-700nm. The detector is a Hammamatsu silicon diode array 1x512 elements: each pixel of array is 0.05x0.2.5 mm and the array is 2.54cm. The spectral dispersion is 0.12nm/pixel. The spectral resolution is about 0.5nm. The grating can be moved by a stepper motor and an internal Hg lamp is used for wavelength calibration. The spectral accuracy is 0.2nm.

Measuring of the microclimatic parameters with automatic meteorological station – continuous measuring of temperature (air and soil), relative humidity, pressure changes and speed of the wind in the 10 m air layer, including the terrain level. A notebook computer will be used for field trials.

Processing and analysis of the photographs and data, seeking for wave structures in the O_3 and NO_2 concentration, comparison with other measurements during an eclipse.

Instrumental observations and measurements can be conducted during the days prior to the eclipse to check the equipment and to monitor the meteorological and environmental conditions of the observation place.

Data processing

The obtained photographs will be scanned with the help of automatic microdensitometer PDS and the images will processed. Special program packs for photometric and polarimetric analysis and methodology of photometric separation of the solar corona components will be applied [22].

The slant column concentrations of the gases under interest are retrieved by the measured spectrum applying the following procedures:

1. Spectral calibration of the measured spectra by means of the Hg lamp.
2. Smoothing of the spectra by FFT.
3. Calculation of the “measured differential cross section”.
4. Spectral alignment between the reference spectrum and the twilight spectra, applying “shift” procedure.
5. Calculation of the gaseous slant column concentration by means of liner least squares regression analysis.

IDL procedures, Fourier techniques and wavelet analysis will be applied for analysis of the climatic data.

Expected results

The following results are expected: determining of the solar corona characteristics, finding of regularities in the O_3 and NO_2 behavior in conditions of reduced solar radiation, and clarifying the dynamical and photochemical processes in the stratosphere and climate of the ground atmosphere.

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