Derivation of Heliophysical Scientific Data from Amateur Observations of Solar Eclipses

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The basic scientific aims and observational experiments included in the complex observational program "Total Solar Eclipse'99" are described in the work. Results from teaching and training students of total solar eclipse (TSE) observation in the Public Astronomical Observatory (PAO) in Stara Zagora and their selection for participation in different observational teams are also discussed. During the final stage, a special system of methods for investigation of the level of pretensions (the level of ambition as to what he/she feels capable of achieving in the context of problem solving/observation) of the students is applied.

Results obtained from the observational experiments are interpreted mainly in the following themes: Investigation of the structure of the white-light solar corona and evolution of separate coronal elements during the total phase of the eclipse; Photometry of the white-light solar corona and specific emission lines; Meteorological, actinometrical and optical atmospheric investigations; Astrometry of the Moon during the phase evolution of the eclipse; Biological and behavioral reactions of highly organized colonies (ants and bats) during the eclipse.

It is also shown that data processing, observational results and their interpretation, presentation and publishing in specialized and amateur editions is a peak in the independent creative activity of students and amateur astronomers. This enables students from the Astronomy schools at Public Astronomical Observatories and Planetariums (PAOP) to develop creative skills, emotional – volitional personal qualities, orientation towards scientific work, observations and experiments, and build an effective scientific style of thinking.

Introduction

The appearance and evolution of rare astronomical phenomena such as total solar eclipses have an exceptional effect on amateur astronomy development. Both professional and amateur astronomers in Bulgaria have been making extensive preparations for the total solar eclipse (TSE) on August 11, 1999, particularly staff at the Public Astronomical Observatories (PAO) and its associated planetariums (PAOP).

The Stara Zagora PAO has a long tradition in observation of solar eclipses. In 1997, the scientific council of PAO together with the active amateur astronomers of Gemma Astroclub determined the basic scientific goals and observational experiments. Before the eclipse, preparations were made according to what phenomena are expected to be seen and the type of equipment needed for observation of these phenomena.

It was also hard work training the observers and estimation of their personal qualities [1, 2].

The difference in the level of theoretical knowledge and observational skills of the students from six problem groups of the Astronomy school (groups of students involved in the three year extra-curriculum Astronomy program) at the Public astronomical observatory in Stara Zagora has been objectively determined by tests in the experimental and control groups.

Original programs and structure of the educative content for each of the problem groups have been worked out [3]. The didactic characteristics of the educational – cognitive method of astronomical observation have been determined by epistemological analysis. A system of didactic tests for studying the development of the critical thinking skills of the students during their participation in astronomical research observations has been developed and experimented [4].

Complex observational programme

The complex observational program includes visual, photographic, photometric and video observations of the Sun and solar corona [5]. The basic goals of the program were as follows:

1. Investigation of the solar corona structure and connection between different coronal elements in integrated light.
2. Photometry of the solar corona in integrated light and specific emission lines (determining the solar corona total brightness, surface brightness distribution, structure of the emission monochromatic solar corona in red (Fe X, λ = 6374 Å), green (Fe XIV, λ = 5303 Å) and yellow (Ca XV, λ = 5694 Å) light.
3. Experiments connected with the atmospheric optics and meteorology.
4. Astrometric observations of the partial phase of the eclipse.
5. Biological observations of the behavior of highly organized animal colonies (ants, bees, bats).

The realization of the complex observational program was considered with the available equipment in PAO, Stara Zagora as well as with those placed at our disposal by outside persons and organizations.

Evaluation of the planned scientific investigations

The coefficient of effectiveness K_{eff} of the observational experiment is calculated by the formula:

$$K_{eff} = \frac{R+Q}{P} \qquad (1)$$

where R is the number of successfully realized observations, Q is the number of high Quality observations, and P is the number of planned observations.

Table 1 Results from the observational experiments.

Result, Experiment	Planned results	Results	Qualitative results	K_{eff}, $K_{eff\ max}$=2	K_v, $K_{v\ max}$=6	Level of claims (LC)
White corona Telescope 3/840mm	36 frames	16 frames	12 frames	0.78	4.4	middle high LC>80
White corona Telescope 63/840mm	36 frames	18 frames	14frames	0.89	4.4	high LC>80
White corona Telescope 63/840mm	36 frames	14 frames	9 frames	0.64	4.4	middle high 40>LC>20
White corona Telescope 63/840mm	36 frames	12 frames	8 frames	0.56	4.4	middle high 80>LC>60
White corona Astrograph 200/1000mm	12 frames	6 frames	3 frames	0.75	5.2	middle low 40>LC>20
White corona Astrograph 200/1000mm	12 frames	12 frames	12 frames	2.00	5.2	high LC>80
Astrometry Telescope 150/2250mm	24 frames	24 frames	22 frames	1.92	5.0	high LC>80
Solar corona polarization Objective F=500mm	36 frames	32 frames	30 frames	1.72	5.4	middle 60>LC>40
Visual estimations: 6 telescopes 60/800mm	I contact 6 estimate	6 estimates	3 estimates	1.5	4.8	middle 60>LC>40
	II contact 6 estimates	6 estimates	5 estimates	1.8	-	
Monochrome Coronal emissions. Tripple astrograph 63/840mm	5303Å 12frames	2 frames	1 frame	0.25	5.4	
	6374Å 12frames	2 frames	1 frame	0.25	5.4	high LC>80
	5694Å 12frames	-	-	-	-	
Corona and sky brightness - Photometer	50 estimates.	45 estimates.	41 estimates.	1.72	5.0	high LC>80

The value coefficient K_v is determined by the method of statistical connecting of criteria [1]. This method is based on a procedure, which evaluates every observational task. The parameters of these tasks are statistically investigated and connected.

$$K_V = \sum_{i=1}^{m} \sum_{j=1}^{n} q_{ij} \qquad (2)$$

q_{ij} - j type criteria weight used for evaluation of group i of observational experiment factors, f_i - number of the factors at the beginning of the experiment.

Investigation of the level of pretensions

A special system of methods for application of the astronomical research observations for development of the critical thinking skills of the students has been formulated. An experiment determining the level of pretensions (the level of ambition as to what he/she feels capable of achieving in the context of problem solving/observation within specified time constraints) of different team observers has been realized. It reveals the individual's preconceptions at objective setting success or failure and the level of observer stability during the specific observation, resulting within the conditions of limited observation time (the duration of the total phase is 144s).

Different versions of textual and observational tests, questionnaires, interviews and the method of expressive appraisals have been used. Two groups of techniques with differences in the procedures and evaluated parameters of the level of pretensions have been applied [6].

In the first group, the students set their objectives in 6 series of problems gradated in a 10-level scale of difficulty. The main focus in this group is centered on the strategic approach of the students rather than the process of problem solving itself, as the significance of strategic approach is shown in the evaluation of experimental data in this regard. Thus, the height, adequacy and stability of his/her level of pretensions are evaluated. Ten, specially prepared cognitive observational problems have been used as a diagnostic material, by which the investigated students have the possibility to be situated in the conditions of real astronomical observational process.

The second group of techniques studies the so-called aim/result discrepancy (i.e. the correlation between students' objectives and factual result). They have no compulsory gradation on the diagnostic material complexity. The observational problems used for the tests have nearly the same difficulty. The relative height of pretensions, which is an indicator of the students' behavioristic orientation towards achieving a successful end result or not, has been evaluated.

Results obtained after processing of data and investigations conducted are summarized in Table 1. The reasons of unrealized experiments were objective, subjective and technical:

The observational experiments with comparatively high value coefficient K_v conducted by observers with a high and middle high level of claims (pretensions) (the level of ambition as to what he/she feels capable of achieving in the context of problem solving/observation) not always obtain observational results with a good quality.

The largest coincidence of the coefficients of effectiveness and value exists in experiments of white light corona photography, astrometry and polarimetry. The observers in the teams are with a high and middle high level of pretensions.

In some cases, teams with a middle and low level of pretensions occasionally obtain an excellent observational result. As a whole, their results and the coefficient of effectiveness are low.

Scientific Results

Investigation of the structure of the white-light solar corona

"Helmet" type streamers and system of polar streamers are the basic details of the solar corona from the total solar eclipse on August 11, 1999 [2].

The solar corona flattening $\varepsilon = 0.19$ and the solar cycle phase $\Phi = 0.66$ are determined with the help of isophot maps. These values illustrate that the corona is pre-maximum type.

The black and white pencil drawings of the corona, made by specially trained observers have been also compared with the schematical picture of the white-light corona obtained from negatives with different exposures [7]. It is evident that dome-shaped structures are well outlined at the bottom of large-scale helmet shaped ones.

Structure of the inner (~ 1.3 $R_\odot$), middle (~ 2.3 $R_\odot$) and outer (~ 3.15 $R_\odot$) corona has been studied [8, 9]. The flattening ($\varepsilon = 0.19$), solar corona type (intermediate, near the solar activity maximum) as well as the disposition of coronal helmet type and radial streamers were determined using about 60 photoimages, made with different exposures. A composite image was obtained and isophotes were determined using 8 images. This composite image was used for obtaining the solar corona flattening.

The electron density N_e distribution up to 3 $R_\odot$ has been obtained and the electron temperature T_e has been determined:

N_e at $r/R_\odot = 1$ is $\sim 1 \times 10^{-9}$ cm^{-3};

N_e at $r/R_\odot = 3$ is $\sim 1 \times 10^{-4}$ cm^{-3};

$T_e = 1.34 \times 10^6$K.

Photometry of the emission solar corona

The distribution of green (5303Å –Fe XIV) and red (6374Å - FeX) coronal emission lines' intensity in polar and equatorial regions is very different. This shows different mechanisms of excitation and distribution of the solar corona's material. For comparison, the white light emission intensity of the solar corona is almost symmetrically distributed. The red-line corona is less intense than the green-line corona, as has long been observed for the corona near maximum solar activity. The ion concentration ratio of FeXIV and FeX is about 1.8 for our observations and is in conformity with the results of other authors.

The sky brightness has been determined - 1.6×10^{-9} from the mean brightness of the uneclipsed Sun before the beginning and after the end of the TSE. Substantial differences have not been obtained in the sky brightness around the zenith, in Sun and anti-Sun direction.

Solar corona photometry in integrated light shows that the emission flow is 1.18×10^{-6} from the emission flow of the uneclipsed Sun (at this day the emission flow from all the solar surface was 6.168×10^{10} erg/cm^2.s).

Meteorological, actinometrical and optical atmospheric investigations

The time variation of microclimatic parameters of near the ground atmospheric layer, and the soil (temperature, humidity, barometric pressure, wind velocity) as well as the condensation processes development during the total phase of the eclipse were recorded. We found that the minimum surface temperature was $t_{min} = 30.6$°C. This was measured 7 min 30sec after the total phase.

A polar diagram of the wind direction is made for August 11, 1999. Measurements were made in 10 minutes intervals. It shows that the wind direction during the total phase changes and the wind begins to blow in the same direction as the direction of motion of the shadow. An absence of wind was registered during the totality.

Barometric pressure changes from 96.957 hPa at the beginning of the eclipse (09:40:00 UT) to 96.89 hPa, measured 30 s after the end of the total phase (11:12:50 UT).

Astrometry of the Moon during the phase evolution of the eclipse

The exact times of the moments of the TSE contacts were determined:

I contact – 09:45:12 UT, II contact – 11:10:08 UT, III contact – 11:12:29 UT, IV contact – 12:32:16 UT.

Twenty two photographs of the partial phases during the eclipse were made by a 150/2250mm telescope. They are used for obtaining the exact lunar disk position in comparison with the solar disk position so as to determine the celestial co-ordinates of the Moon during the eclipse.

The boundaries of the total lunar shadow path on the Earth's surface have been determined - south of the Bogdantsi station and north of the Hursevo station. Geographical co-ordinates are: $\varphi = 43°36.25'$, $\lambda = 26°50.35'$. A 1850m displacement of the lunar shadow is registered south of the previously determined boundaries.

The moments of Baily's beads appearance were determined: before the beginning of the total phase -11:10:04 UT, and after its end - 11:12:31 UT.

Biological observations

The circadian bat system depends on the normal day/night cycle. During the TSE, circadian nonrhythmicity was

observed in a bat colony composed of about 2500 specimens of Myotis bechsteinii and Rhynolophus hipposideros bats. They live in caves placed situated in the coastal part of the town of the Kavarna region. Data have been interpreted as a total solar eclipse effect on the nonbiotic factors (temperature, humidity, barometric pressure, wind velocity in cave galleries, luminosity).

The most possible mechanism started the action of bats' time-giver is the change of the temperature, barometric pressure and humidity in the contact band between the cave's zones of constant and variable temperatures. This small number of bats in the region which still react to the outside changes of the environment plays the role of "active indicators" of the changed circadian rhythms' factors. As these factors are relatively time-delayed their influence on the bats' perceptions is also delayed.

Subsequently, these active representatives become initiators of the activity of 25% from the bats in the colony.

Publication

The results have been generalized in 12 scientific papers. In the final process of paper preparing, only 35 % of the students involved in the program showed development of the critical thinking skills – work with texts, data processing, making conclusions, presenting of contributions.

Conclusion

The didactic effectiveness of new methods of involving individual students in the Stara Zagora Public astronomical observatory in educational research activity during the total solar eclipse on August 11, 1999 has been investigated.

A system of didactic tests for studying the development of the critical thinking skills of the students during their participation in astronomical research observations has been developed and experimented.

The TSE'99 complex observational program includes visual, photographic, photometric and video observations of the Sun and solar corona, experiments connected with the atmospheric optics and meteorology, astrometric observations of the partial phase of the eclipse and biological observations.

Evaluation of the planned scientific investigations is based on a procedure, which evaluates every observational task.

A new training model based on the level of pretensions determining of the different observers in the teams has been applied. It reveals individual stereotypes at goals' choice, reactions with respect to the success and the level of individual observer steadiness in conditions of short observational time (144 sec is the total phase duration). In order to determine the level of pretensions of the observers of different groups, observational tests, inquiries, interviews, and expert evaluations method have been used.

Two groups of techniques with differences in the procedures and evaluated parameters of the level of pretensions have been applied. Results obtained after processing of data and investigations conducted are summarized in Table 1.

Scientific results from the investigation are discussed.

The participation of students from the Astronomy school at the Public astronomical observatory in Stara Zagora in National Observational programs develop their creative and critical thinking skills, emotional – volitional personal qualities.

REFERENCES

[1] A. Stoev, "Scientific data derived from amateur astronomical observations", *Physics*, Vol. 1, 2001, pp. 59-64, (in Bulgarian).

[2] A. Stoev, "Visual, photographic, photometric, polarization and other observations during the 1999 total solar eclipse done by the People's Astronomical Observatory at Stara Zagora", in: *First Results of 1999 Total Solar Eclipse Observations*, D.N.Mishev and K.J.H. Phillips (eds.), Professor Marin Drinov Publishing House, Sofia, 2002, pp. 137-142.

[3] A. Stoev, N. Kiskinova, P. Gancheva, "Special programme for education and selection of observers of the August 11, 1999 total solar eclipse. In: *Total solar eclipse 1999 - observational programmes and coordination", Proceedings*, Recol, Haskovo, 1999, pp.138-141, (in Bulgarian).

[4] A.Stoev, P. Muglova, "Developing critical thinking skills by active observations in the process of teaching in Public astronomical observatories", 25th General Assembly of the International Astronomical Union, 13-26 July 2003, Sydney, Australia, in: *"Teaching and Learning Astronomy: Effective Strategies for Educators Worldwide"*, J.M. Pasachoff and J.R. Percy (eds.), Cambridge: Cambridge University Press, 2005.

[5] Stoev A., et al., "Complex observational programme of the Yuri Gagarin Public Astronomical Observatory and STIL", BAS, Stara Zagora Department for the August 11, 1999 total solar eclipse, in: *"Total solar eclipse 1999 - observational programmes and coordination", Proceedings*, Recol, Haskovo, 1999, pp. 133-137 (in Bulgarian).

[6] A. Stoev, "Creative abilities development conducting amateur research observations in the astronomy school", 4th General Conference of the Balkan Physical Union, 22-25 August 2001, Veliko Turnovo, *Balkan Physics Letters*, 2001, pp. 156-160.

[7] V.Kulijanishvili, "Eclipse observations of the solar corona by the expedition of the Abastumani astrophysical observatory", in: *First Results of 1999 Total Solar Eclipse Observations*, D.N.Mishev and K.J.H. Phillips (eds.), Professor Marin Drinov Publishing House, Sofia, 2002, pp. 103-110.

[8] A.Stoev, "Structure of the solar corona during the 1999 total solar eclipse", in: "*First Results of 1999 Total Solar Eclipse Observations*", D.N.Mishev and K.J.H. Phillips (eds.), Professor Marin Drinov Publishing House, Sofia, 2002, pp. 143-150.

[9] P. Muglova, A. Stoev, "Structure of the emission monochromatic solar corona in the green (5303Å) and red (6374Å) line", in: "*First Results of 1999 Total Solar Eclipse Observations*", D.N.Mishev and K.J.H. Phillips (eds.), Professor Marin Drinov Publishing House, Sofia, 2002, pp. 151-154.