Some Results for the Visual Observations and Spectrophotometering of the Earth's Atmosphere Twilight Glow from the 'Soyuz-5' Spacecraft

By K. Ya. Kondratyev, B. V. Volynov, A. P. Galtsev, O. I. Smokty and E. V. Khrunov [1])

Summary – The scheme of the experiment aiming at spectrophotometering of the twilight horizon is described. The first experience of spectrophotometering with the help of a handheld spectrograph is discussed. It is shown that such observations are useful for determining the vertical aerosol profile in the atmosphere.

Introduction

Rapid advances in exploring near space with the automatic apparatus on artficial Earth's satellites, manned space vehicles and interplanetary stations permit at present the statement and solution of a number of important problems on space atmospheric optics both of theoretical and applied character.

In this connection for a number of years the corresponding visual observations have been carried out by Soviet and American astronauts and black-and-white and color photographs of the terrestrial atmosphere twilight horizon at different solar depression angles obtained [1]–[4] [2]). It will be noted, however, that, at the best, the twilight glow photography was performed using two or three light filters, which did not allow one to study a full picture of the spectral brightness distribution over the twilight sky, nor to establish its dependence on the variations of atmospheric optical parameters.

On the other hand, the development of theoretical investigations based on the use of analytical and numerical methods for the solution of the radiative transfer equations in the aerosol spherical atmosphere enabled one to derive a sufficiently full information on the angular, spacial and spectral distribution of the twilight glow brightness for different models of the vertical distribution of the atmospheric optical parameters [4]–[9]. Hence, there appeared the necessity to conduct the complex optical experiment from space which would permit the study of the spectral (color), angular and spacial evolution of the twilight atmospheric brightness picture. This programme has been, first, realized during the 'Soyuz-5' space mission. Within the field of optical investigations it stipulated spectrophotometering of the terrestrial

[1]) Institute of Atmospheric Physics, Leningrad State Univsersity, Leningrad (U.S.S.R.).

[2]) Numbers in brackets refer to References, page 163.

atmosphere twilight glow over the wavelengths range of 400–650 mμ as well as conducting the complex of the corresponding visual observations. Sight geometry of the twilight atmosphere is represented in Fig. 1.

1. To conduct the experiment the use was made of the hand spectrograph specially designed for the purpose and furnished with the tele-objective, which permits spectrophotometering of remote objects with the spectral resolution of 5 mμ and the angular resolutionin the order of 2′. The optical scheme of the instrument is represented in Fig. 2.

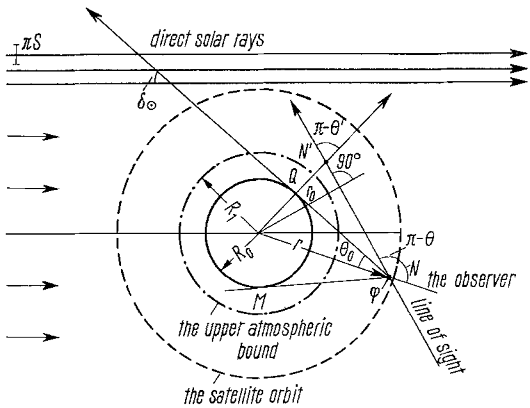

Figure 1
Sight geometry of the twilight atmosphere from spacecraft

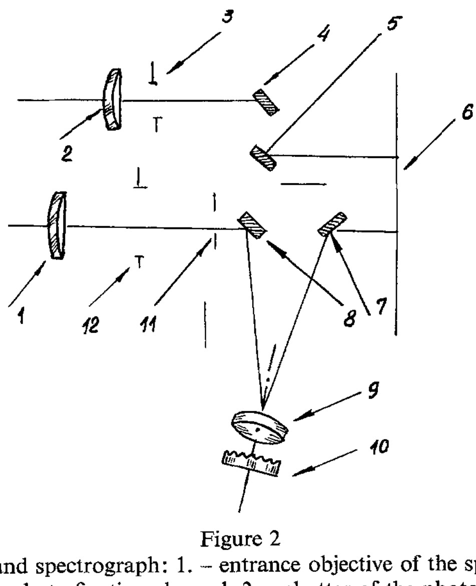

Figure 2
Optical scheme of the hand spectrograph: 1. – entrance objective of the spectrograph channel, 2. – Entrance objective of the photo-fixation channel, 3. – shutter of the photo-fixation channel, 4, 5, 7, 8 – flat rotating mirrors, 6. – photo-film, 9. – collimating objective, 10. – diffraction grating, 11. – entrance slit of spectrograph, 12. – shutter of the spectrograph channel.

The operating programme for the hand spectrograph involved the Sun-directed photography of the Earth's atmosphere twilight glow from the moment of its appearance up to the full emersion of the spacecraft on the sunlit side of the Earth. The visual observations comprised the estimation of the vertical brightness evolution and the twilight glow color, with the Sun emerging from the horizon. According to the programme, the visual observations and spectrophotometering have been fulfilled on three loops: 2, 6, 15. The optical experiment was carried out under the conditions of the cloud-free atmosphere (loop 2), continuous cloudiness (loop 6) and the broken cloudiness (loop 15). Over the experimental area a stable synoptical situation (the lack of hurricanes, storms etc.) was observed.

2. The visual observations in the cloudless atmosphere which preceded spectrophotometering can be summarized as follows. At larger solar depression angles the red-orange hues are observed at the Earth's surface (the edge being distinctly seen). With the height of sight layer increasing, the color is smoothly transformed into the orange-yellow attached to which is a narrow dark-blue band of decreased brightness situated, approximately, at the height equal to $\frac{1}{3}$ of the visible size of the glow. The dark-blue band is sharply changed into the light pale-blue color which, in turn, is transformed into the dark-blue and violet at high altitudes. With the solar depression angle decreasing, the glow brightness increases and the dark-blue band disappears, the saturation of color hues for the twilight glow increasing. This color picture differs, by some details, from the corresponding descriptions by P. FEOKTISTOV [1], V. V. NIKOLAEVA-TERESHKOVA [2], J. MCDIVITT and E. WHITE [4]. This emphasizes the different character of the meteorological situation during the visual observations from space-vehicles 'Soyuz-5', 'Vostok-5', 'Voskhod' and 'Gemini-4', and testifies to the fact that the colorimetric data as obtained from space are sensitive indicators of the vertical nonuniformities of the Earth's atmosphere.

3. From spectrophotometering on January 15 (loops 2, 6) and January 16, 1969 (loop 15) at 12 h 52 m, 18 h 23 m and 07 h 23 m Moscow time, accordingly, 15 frames containing the spectra and photographs of the twilight glow have been obtained under different conditions, with the Sun emerging from the horizon. The geographical coordinates of 'Soyuz-5' at the moment of spectrophotometering were as follows: loop 2, 30°S, 157°4′E (near the eastern coast of Australia); loop 6, 51°69′S, 147°13′E (the region of the Auckland islands); loop 15, 4, 29°S, 131°66′E (the region of the island New Guinea). The photography was directed to the Sun, the spectrograph entrance slit azimuth relative to the Sun being equal to 8°, and the entrance slit situated normally to the horizon.

The spectra have been processed with the spacing against the height equal to 1 km, and against the wavelength equal to 10 mμ. The altitude fixation of spectral curves was made from the glow photograph, the absolute error in determining a zero level of the altitude fixation being in the order of 2 km. The accidental error in determining the absolute brightness values is 10%.

4. The results obtained can be summed up as follows. Near the Earth's surface the basic contribution to the twilight glow brightness is made by the long-wave radiation. With the height of the sight layer increasing, the atmospheric density drops and the twilight glow brightness is determined by scattering and absorption of the short-wave radiation. The maximum value for the twilight glow brightness falls on the wavelength of $\lambda \simeq 480$ mμ. At the wavelength of $\lambda \simeq 600$ mμ the brightness minimum due to the ozone absorption in the Chappuis band is observed. The depth of this minimum depends on the height of the atmospheric layer involved above the Earth's surface. Spectral brightness is strongly dependent on the sight direction azimuth and the solar depression angle sharply increasing with the decrease in the latter. The height corresponding to the spectral brightness maximum is also dependent on the solar depression angle and the wavelength decreasing with the increase in the latter.

5. The analysis of the brightness curves obtained suggests the lack of the marked brightness depressions due to aerosol layers localized at different atmospheric levels (for instance, 11 and 19 km). Since it does not correspond to the conclusions of paper [2] the numerical calculations have been made to determine the influence of the aerosol concentration in the layers and the solar depression angle on the absolute values of the depressions concerned and on the color picture of the glow measured. It turn out that the double increase in the aerosol volume concentration at the altitude of 20 km (the ELTERMAN's model [10]) does not cause noticeable depressions on the corresponding brightness curve, which appear only with the increase of the volume concentration at this altitude by factor of 4. The conventional value of the aerosol volume concentration given by the ELTERMAN's model [10] gives rise to the depressions on the monochromatic brightness curves only at the solar depression angle surpassing 3°.

From the analysis of the colorimetrical calculated data as derived for the ELTERMAN's model [10] one can conclude that at small solar depression angle the twilight sky color is substantially influenced by ozone ('blueing' of the twilight sky within the height range of 25–30 km). The brightness depression due to aerosol layer occurs at large solar depression angles and will be perceived by the observer from space as dark bands of decreased brightness.

6. Comparison of the experimental values for the twilight glow brightness with the calculated ones as obtained in the approximation of the primary scattering for the ELTERMAN's model [10], 'Soyuz-5' orbital parameters and sight direction (corresponding to the optical experiment from space) made it possible to evaluate the contribution of multiple scattering to the twilight glow brightness at different altitudes. As could be expected, the contribution of multiple scattering to the twilight glow brightness near the Earth's surface turned out determinant. With the increase in the height of sighting layer the part of primary scattering increases (above 30–40 km the experimental and calculated brightness curves practically coincide (see Fig. 3).

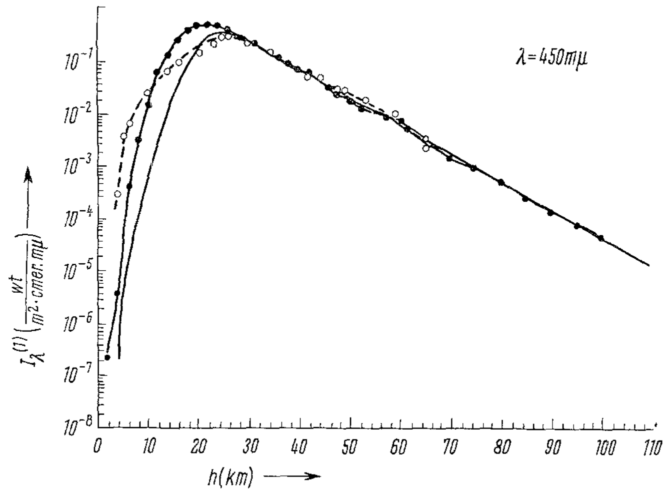

Figure 3
Experimental and calculated values for the monochromatic brightness of the Earth's atmosphere twilight glow (the wavelength $\lambda = 450$ mμ; loop 2, the orbitral spacecraft altitude $h = 252{,}3$ km; the solar depression angle $\delta_\odot = 0°$, azimuth of sight direction $\varphi = 8°$). ——— ELTERMAN's model [10] (primary scattering), × — × Molecular atmosphere (primary scattering), ∘—∘ Experimental data ("Soyuz-5").

Conclusion

The results obtained permit the estimation of the optimum possibilities as to the photography and spectrophotometering of the twilight atmosphere from spacecraft with the purpose of solving the inverse problems of atmospheric optics. At small solar depression angles the vertical brightness depressions for the twilight aerosol atmosphere are either small or altogether missing, which complicates the solution of the problem on the restoration of the vertical profile of the scattering aerosol coefficient from the twilight glow brightness as measured from the spacecraft. However, the color picture of the twilight glow is rather sensitive to the presence of such vertical nonuniformities as, for example, the ozone layer. Therefore in the solution of the inverse problems on atmospheric optics one should combine the colorimetric analysis of the optical data obtained from space with the analysis of the absolute depression values on the curves for the twilight glow monochromatic brightness. Hence, of very great importance is to conduct the space experiment on the independent determination (with the help of direct sounding) of various characteristics of the atmospheric vertical structure (the vertical profiles of ozone, aerosol etc.) with the simultaneous estimation of the altitude evolution of the twilight sky color.

REFERENCES

[1] K. P. FEOKTISTOV, G. V. ROSENBERG, A. B. SANDROMIRSKY, V. N. SERGEEVICH and D. A. So-

NECHKIN, *Some Results of the Optical Observations from the 'Voskhod' Spacecraft*, in *Outer Investigations* (Izd. Nauka. Moscow 1965).

[2] G. V. ROSENBERG and V. V. NIKOLAEVA-TERESHKOVA, *Stratospheric Aerosol from Spacecraft Measurements*, Izv. Acad. Sc. USSR, ser. atm. and ocean, physics *1*, 4 (1965).

[3] W. M. SCHIRRA, *Air Communications of the MS-8 Flight. Results of the Third US Manned Orbital Space Flight*, NASA Publ. SP-12 (1962).

[4] L. DUNKELMAN, I. R. GILL, J. A. MCDIVITT, F. E. ROACH and E. H. WHITE, *Geoastronomical Observations, in Manned Space Flight Experiments Symposium*, Gemini III and IV, NASA Publ. (1965).

[5] A. YA. DRIVING, I. M. MIKHAILIN, G. V. ROSENBERG, A. B. SANDROMIRSKI and G. I. TRIFONOV, *Photometric Analysis of the Twilight Glow Photograph as Obtained from the 'Vostok-6' Spacecraft*, Izv. Acad, Sci. USSR, ser. atm. and ocean physics *2*, 6 (1966).

[6] C. L. MATEER, I. V. DAVE, L. DUNKELMAN and D. C. EVANS, *Evidence of Upper Stratospheric Dust Layer in a Satellite Twilight Color Photograph*, NCAR, No. 465 (1968).

[7] O. I. SMOKTY, *Light Scattering in the Aerosol Spherical Atmosphere*, Izv. Acad. Sci. USSR, ser. atm. and ocean. physics *5*, 1 (1969).

[8] O. I. SMOKTY, *On the Approximate Determination of the Twilight Glow Brightness of the Real Terrestrial Atmosphere in the region of 0.40–1.06 μ*, Izv. Acad. Sci. USSR, ser. atm. and ocean. phys. *5*, 8 (1969).

[9] G. I. MARCHUK and G. A. MIKHAILOV, *Results for the Solution of some Problems on Atmospheric Optics by the Monte-Carlo Method*, Izv. Acad. Sci. USSR, ser. atm. and ocean. phys. *3*, 4 (1967).

[10] L. ELTERMAN, *UV, Visible and IR Attenuation for Altitudes to 50 km*, AFCRL-68-0153, Environmental Res. Paper, No. 285 (1968).

(Received 15th June 1970)