# 21. COMMISSION DE LA LUMINESCENCE DU CIEL

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## INTRODUCTION

Included in this draft report are discussions of papers on the night airglow and the twilight glow. Because of the fact that Commission 21 in collaboration with Commission 22 is sponsoring a colloquium in Honolulu on the Zodiacal Light and the Interplanetary Medium from 28 January to 2 February 1967, (one month after this draft report is due) it is planned to postpone definitive discussion of the zodiacal light, gegenschein and the integrated starlight until the time of the general assembly. We are omitting general discussion of the aurora except for some low and mid-latitude phenomena which have both airglow and auroral characteristics. Research reports based on work done in the Soviet Union have been reviewed by N. N. Shefov. His resumé is included as a part of the present report.

The period between the XIIth and the XIIIth General Assemblies includes much of the IQSY (International Year of the Quiet Sun) from 1 January 1964 to 30 December 1965. The level of night airglow research activity during the IQSY was somewhat lower (19 reporting stations) than that during the earlier IGY (28 reporting stations). During the triennium the space age has matured and a beginning has been made on significant observations from orbiting spacecraft. Observations have also continued from rockets as well as balloons.

Recently there has been a polarization of interest in the nightglow by geophysicists, in contrast with the earlier studies in which the astronomical fraternity maintained the initiative. This is a natural evolution as the interest in the nightglow tends to concentrate on the atmospheric reactions and processes responsible for the emissions. The earthbound astronomer maintains his interest because of the fact that the nightglow constitutes a foreground 'haze' which he must pierce. As we proceed to astronomy from spacecraft beyond the nightglow layers we may anticipate that the nightglow will come to be more and more associated with geophysics until such a time as we begin to accumulate data of atmospheric radiations from other planets.

Before beginning the detailed report it seems appropriate to express the personal sorrow and to acknowledge the professional loss in the death of the distinguished former president of Commission 21, Dr Daniel Barbier (1907-65) (*Annales de Géophysique*, **21**, 295, 1965).

## GROUP DISCUSSIONS, COLLOQUIA AND SYMPOSIA

During the triennium group discussions have been held, or are planned, as follows:

1965, April 14–16, Boulder, Colorado, U.S.A.

Group discussion participated in by some 70 persons. Subject 'Middle and Low Latitude

Atmospheric Emissions and the Ionosphere'. The deliberations were dedicated to the memory of Dr Daniel Barbier. Proceedings have been prepared by F. E. Roach and K. D. Cole in a non-referencable form which can be obtained by request to F. E. Roach, ESSA, Boulder, Colorado.

1965, August 16–20, Cambridge, Massachusetts, U.S.A.
International Symposium on Aeronomy organized by the International Association of Geomagnetism and Aeronomy (UGGI). Many of the papers have been published in *Ann. Géophys.*, **22**, no. 2, 1966.

1965, September, São Jose dos Campos, Brazil.
Second international symposium on Equatorial Aeronomy. Proceedings and abstracts of the papers have been published (F. de Mendonca, editor) as CNAE-LAFE 32, November, 1965. Many of the full papers have been published in *Ann. Géophys.*, **22**, no. 3, 1966.

1966, August, University of Keele, England.
Advanced Study Institute on Aurora and Airglow. A compilation of proceedings and papers is in press (Billy M. McCormic, editor), Reinhold, 1967.

1967, January 30–February 2, Honolulu, Hawaii, U.S.A.
An international colloquium sponsored by Commissions 21 and 22 of the IAU on The Zodiacal Light and the Interplanetary Medium. It is planned to publish the papers (J. L. Weinberg, editor).

1967, July 17–21, London, England.
Fourth and final IQSY Assembly.

### A. AIRGLOW, GENERAL

In preparing this draft report, the procedure was to scan systematically the following journals for 1964, 1965, and 1966: *Annales de Geophysique*, *Astrophysical Journal*, *Journal of Atmospheric and Terrestrial Physics*, *Journal of Geophysical Research*, *Planetary and Space Science*, *Space Science Reviews*. This was supplemented by lists furnished by several colleagues. It is planned to circulate the draft report widely with the hope that the bibliography can be extended to include papers that may have been missed in the first screening.

For convenience the bibliography is arranged to correspond to the text. At the end of each section of the bibliography papers by Soviet colleagues are indicated according to the listing by Shefov.

Of particular interest in the listing of general airglow papers is the comprehensive report by Mme Glaume (1965, reference **A5**). The paper comprises a detailed study of what may be considered the 'classical' nightglow radiation, the 5577 Å line of atomic hydrogen. Mme Glaume discussed the temporal variations on the basis of the large library of observational data from Haute-Provence. She also made a comparison of the observations from many stations, using north-south intensity gradients to call attention to evidence that 5577 Å maximizes in mid-latitudes, under the influence or control of the Earth's magnetic field.

In addition to the papers which deal with specific problems attention is called to the broader review papers (**A2**, **A6**, **A14**, **A15**).

### B. TROPICAL AIRGLOW AND THE IONOSPHERE

The references listed in this section are heavily weighted to the ionosphere, which needs some explanation since this is a report to astronomers. The reason is as follows. In the tropics the nightglow 6300 Å and one photometric component of 5577 Å are emitted in the F region of the ionosphere by a photochemical process that is directly associated with the equilibrium that maintains the ionospheric electron balance.

$$\begin{cases} O_2 + O^+ \rightarrow O_2^+ + e \\ O_2^+ + e \rightarrow O + O + 6{\cdot}96\ \text{eV} \end{cases}$$

The second of these reactions is capable of exciting the atomic oxygen to the $^1D$ (1·96 eV) and/or the $^1S$ (4·16 eV) states from which the 6300 Å and/or 5577 Å emissions originate. It is possible to derive a relationship between the brightness of the radiations (e.g. 6300) and ionospheric parameters customarily measured on ionograms (reference **B26**). This relationship (known as the 'Barbier formula' after its discoverer) is

$$Q_{6300} = A + B\,(f_0\,F_2)^2 \left[\exp - \left(\frac{h'F - 200}{H}\right)\right]$$

where $Q_{6300}$ is the brightness of the 6300 emission (usually in rayleighs), $A$ is an additive constant corresponding to a background brightness, $B$ is a constant which essentially puts the results in rayleighs, $f_0F_2$ is the so-called critical frequency, the square of which is proportional to the F-region peak electron density, $h'$F is the 'virtual height' as measured on an ionogram and $H$ is a scale height, approximately 40 km in the F region.

In the tropics both the nightglow and the ionosphere exhibit dynamic changes. For many years it has been known that the ionosphere has maximum electron densities some 15° from the geomagnetic equator—a phenomenon which is known as the equatorial anomaly. During the triemmium under review a number of papers have been produced on the anomaly (**B1, 6, 7, 8, 9, 10, 11, 16, 17, 18, 19, 20, 22, 23, 24, 28, 30, 32, 33, 35, 36**). The other papers listed discuss the other aspect of the problem, namely the photometric observations of the nightglow which is directly associated both with the above mentioned photochemical reactions and with the morphology of the equatorial ionospheric anomaly.

### C. MID-LATITUDE STABLE AURORAL ARCS

The phenomenon which, in the literature has been referred to as 'l'arc auroral stable', M-arc, SAR-arc, has the 'auroral property' of alignment under the control of the geomagnetic field and the airglow property of a low level of excitation. The conference in Boulder (14–16 April 1965) referred to above was devoted, in large part, to a discussion of its properties. It is now apparent that the occurrence of the arcs follows the sunspot cycle as does the visible aurora. Thus the period between the XIIIth and XIVth General Assembly of the IAU should see a revival of occurrence of the arcs. During the triennium under review they have been sparse. Attention is called especially to the papers by K. D. Cole in the attached bibliography.

### D. EXCITATION OF 6300 Å [OI] BY PHOTOELECTRONS

For decades observers have noted that the 6300 Å emission often has a pre-dawn enhancement which is not at all symmetrical with the post-twilight decrease in intensity. The paper by K. D. Cole (**D2**) explains the pre-dawn enhancement as the result of the travel of photoelectrons from the magnetically conjugate region where local dawn starts earlier than at the observing station. The prediction has been confirmed by H. C. Carlson at the Arecibo station in Puerto Rico (**D1**).

### E. NIGHTGLOW VARIATIONS, TEMPORAL AND SPATIAL

The papers listed under this category include discussions of diurnal, seasonal and sunspot cycle variations. Of particular interest are studies of geographical changes and the reader is referred back to the discussion of Mme Glaume's paper (**A5**) under the Airglow, General, discussion.

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### F. HYDROGEN AIRGLOW

The fluorescent excitation of atomic hydrogen in the outer atmosphere has received significant attention during the triennium. Our Soviet colleagues have been especially active in these studies.

Attention is called to the interesting discussion by Kondo and Kupperian (**F7**) of a suggested interaction between neutral hydrogen and charged particles in the radiation belt based largely on the observational results of Winter (**F8**).

### G. AERONOMY AND EXCITATION PROCESSES

The large number of papers cited in this section illustrates the point made earlier that the night airglow center of attention is frequently more geophysical than astronomical. During the triennium the reactions mentioned in section B have been established as of prime importance both in the ionospheric balance and of the emission of the high nightglow. These reactions are discussed in references (**G4, 8, 14, 15, 16, 21, 22, 26, 27**).

An important paper on the rate coefficient of the Chapman reaction ($O + O + O \rightarrow O_2 + O^*$) is that of Young and Black (**G28**; see also **G2**). The question of excitation by energetic particles is actually one of the extension of auroral type mechanisms equatorward of the auroral zone (pertinent references: **G1, 5, 7, 11, 12, 23, 24**).

### H. $N_2^+$ IN THE NIGHTGLOW

The $N_2^+$ band at 3914 Å is characteristic of auroras and of the twilight. Its possible presence in the nightglow is difficult to determine for two reasons: (1) if present at all it is extremely faint and (2) contamination by either auroral or twilight emissions is an observational hazard. Three of the papers cited illustrate the difficulty and the disagreement of observers. Broadfoot and Hunten (**H1**), working with relatively high spectroscopic resolution, report that $N_2^+$ 3914 Å has an intensity *less than* one rayleigh. O'Brien, *et al.* (**H4**) from rocket observations report some five rayleighs. Yano (**H5**) from spectrographic observations in Australia has reported about ten rayleighs.

### I. HYDROXYL (OH) NIGHTGLOW

This very intense radiation has been studied with considerable concentration by the Soviet observers (note the eleven references in Shefov's list). It is hoped that this summary may inspire all observers to give more attention to this interesting phenomenon.

### J. DOPPLER TEMPERATURES

The determination of temperature based on the measurement of the Doppler width of a spectral line requires high resolution interferometric techniques. Because of the meticulous technology involved in such measurements there have not been extensive measurements on anything like a synoptic basis. The references cited illustrate that good results have been obtained. Of particular interest during the next sunspot maximum will be measurements of 6300 Å temperatures in midlatitude auroral arcs (see section C above).

### K. INSTRUMENTATION AND TECHNIQUES

Absolute calibration of photometers for low light levels continues as a problem (**K2, 5**). Height measurements by the van Rhjin method are discussed in references **K1** and **K3**. A successful use of triangulation in determining nightglow heights is described in **K6** and **K7**.

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## L. ROCKET AND SATELLITE OBSERVATIONS

This triennium has witnessed significant observations of the airglow from orbiting spacecraft. An effort has been made to record a definitive list of references (**L6, 7, 8, 9, 10, 11, 12**) in which descriptions occur of the nightglow as seen by astronauts. The references cited are in general available for a moderate fee by application to the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C., 20402. The observations may be summarized by the statement that all of the Mercury and Gemini astronauts have seen the 100-kilometer airglow layer below the spacecraft usually as a structureless band about 2° above the horizon for orbits below 200 kilometers. In the absence of moonlight it is much more conspicuous than the solid earth surface. Two of the astronauts (Schirra and Cooper) have reported sightings at higher elevations than the spacecraft which have been tentatively ascribed to the F-region nightglow. For photographs from a rocket of the 100-kilometer nightglow see reference **L4**.

An interesting observation (reference **L2**) is the isolation of the nightglow 6300 Å emission layer together with a 5577 Å emission layer in the F region, much fainter than the 5577 Å emission near 100 kilometers. This confirms what had been deduced from tropical nightglow studies where sporadic changes in 6300 Å nightglow are accompanied by simultaneous changes in 5577 Å (see section B).

## M. TWILIGHT GLOW

Two excellent review papers (**M1, 2**) are in press. During the period under review some 60 papers on the twilight glow have been published (see the extensive bibliography in **M2**). Attention is called to the significant activity in this field by Soviet investigators.

FRANKLIN E. ROACH
*President of the Commission*

## BIBLIOGRAPHIE

### *A. Airglow, General*


1. Abbott, W. N. 1964, Possible correlations between sporadic-E and low-altitude airglow emission of 5577 Å in median latitudes, *J. atmos. terr. Phys.*, **26**, 776.
2. Barbier, D. 1964, Airglow, *Res. Geophys.*, **1**, Chapter 16, Mass. Inst. Tech.
3. Barbier, D. 1965, La lumière du ciel nocturne aux Iles Kerguelen, *Ann. Géophys.*, **21**, 299.
4. Bellew, W., Silverman, S. 1966, General behavior of 6300 Å [O I] at Sacramento Peak, New Mexico, *Planet. Space Sci.*, **14**, 407.
5. Glaume, J. 1965, Étude de la raie 5577 Å de l'oxygène dans la luminescence atmosphérique nocturne, *Ann. Géophys.*, **21**, 1.
6. Hunten, D. M. 1967, Spectroscopic studies of the twilight airglow, *Space Sci. Rev.*, **6**, 493.
7. Huruhata, M. 1965, Lunar tidal effect on the oxygen green line in the night airglow, *J. geophys. Res.*, **70**, 5979.
8. Huruhata, M. 1964–1965, Japanese contribution to the IQSY.
9. Kulkarni, P. V. 1965, On the height of the 5577 Å [O I] airglow layer in Hawaii, *Ann. Géophys.*, **21**, 58.
10. Lagos, P. 1964, The airglow 6300 Å [O I] emission the luminosity profile with varying scale height, *J. atmos. terr. Phys.*, **26**, 325.
11. Markham, T. P., Anctil, R. E. 1966, Airborne night airglow measurements in the south atlantic magnetic anomaly, *J. geophys. Res.*, **71**, 997.
12. Murcray, W. B. 1963, Infrared radiation from the atmosphere over the Arctic Ocean, *Science*, **141**, 802.
13. Nguyen-Huu, Doan 1964, Étude spectrophotométrique de la lumière ciel nocturne et crépusculaire dans le visible, *Ann. Géophys.*, **20**, 1.

14. Roach, F. E. 1964, The light of the night sky: astronomical, interplanetary and geophysical, *Space Sci. Rev.*, **3**, 512.
15. Roach, F. E., Smith, L. L. 1967, The worldwide morphology of the atomic oxygen nightglows, in Aurora and Airglow, Proc. of Aurora and Airglow Advanced Study Institute, Ed. Billy M. McCormic, Reinhold, p. 29.
16. Tanabe, H. 1964, Zodiacal light and airglow components at 5300 Å, *Publ. astr. Soc. Japan*, **16**, 324.
17. Tanabe, H. 1964, Further evidence for the existence of an airglow radiation near 5300 Å independent of 5577 Å line, *Publ. astr. Soc. Japan*, **16**, 340.
18. Pertinent papers by Soviet authors: Shefov's list, No. **7, 13, 15, 16, 24, 27, 57, 58**.

## *B. Tropical airglow and the ionosphere*

1. Awajobi, O. A. 1965, On the ionspheric F2-region equatorial anomaly, *J. atmos. terr. Phys.*, **27**, 1309.
2. Barbier, D. 1964, Nouvelles observations de la raie rouge du ciel nocturne en Afrique, *Ann. Géophys.*, **20**, 22.
3. Barbier, D. 1964, L'observation optique de la couche F de l'ionosphère, *Scientia*, Sept.-Oct.
4. Barbier, D. 1964, Observations photométrique d'une perturbation de la haute atmosphere, *Astrophys. norw.*, **9**, 55.
5. Barbier, D. 1965, Deux phenomènes particuliers présentés par la raie rouge de la lumière du ciel nocturne, *Ann. Géophys.*, **21**, 228.
6. Baxter, R. G. 1964, On the theoretical effects of electrodynamic drift in the equatorial F2 layer, *J. atmos. terr. Phys.*, **26**, 711.
7. Baxter, R. G., Kendall, P. C., Windle, D. W. 1965, Power series solution of the F2-layer diffusion equation, *J. atmos. terr. Phys.*, **27**, 1263.
8. Brace, L. H., Spencer, N. W. 1965, Detailed behaviour of the midlatitude ionosphere from the Explorer XVII satellite, *Planet. Space Sci.*, **13**, 647.
9. Bramley, E. N. 1966, Plasma diffusion in the ionosphere, *J. atmos. terr. Phys.*, **28**, 681.
10. Bramley, E. N., Peart, M. 1964, Diffusion and electromagnetic drift in the equatorial F2 region, *J. geophys. Res.*, **69**, 4609 (also in 1965, *J. atmos. terr. Phys.*, **27**, 1201).
11. Burkard, O. M. 1966, Some remarks on papers concerning the geomagnetic anomaly of the F2-layer, *J. atmos. terr. Phys.*, **28**, 1129.
12. Carman, E. H. 1964, Dependence of [O I] 6300 Å airglow on latitude as observed from Townsville, Australia, *Nature*, **201**, 595.
13. Carman, E. H. 1965, Seasonal trends in the latitude correlation between ionospheric parameters and [O I] 6300 Å airglow observed from Townsville, *J. atmos. terr. Phys.*, **27**, 329.
14. Carman, E. H., Gibson-Wilde, B. C. 1964, Seasonal variation of the [O I] 6300 Å airglow at Townsville from isophote sky maps, *J. geophys. Res.*, **69**, 487.
15. Carman, E. H., Kilfoyle, B. P., Gibson-Wilde, B. C. 1964, Pattern of the [O I] 6300 Å airglow emitting regions at Townsville, *J. geophys. Res.*, **69**, 4725.
16. Chandra, S. 1964, Plasma diffusion in the ionosphere, I., *J. atmos. terr. Phys.*, **26**, 113 (II. 1965, *J. atmos. terr. Phys.*, **27**, 1159).
17. Chandra, S., Goldberg, R. A. 1964, Geomagnetic control of diffusion in the upper atmosphere, *J. geophys. Res.*, **69**, 3187.
18. Duncan, R. A. 1964, Electrodynamic lifting and the equatorial F region of the ionosphere, *J. geophys. Res.*, **69**, 3741.
19. Gliddon, J. E. C., Kendall, P. C. 1964, Perturbation of a model F2-region by a small arbitrary time-dependent electrodynamic drift, *J. atmos. terr. Phys.*, **26**, 721.
20. Goldberg, R. A., Kendall, P. C., Schmerling, E. R. 1964, Geomagnetic control of the electron density in the F region of the ionosphere, *J. geophys. Res.*, **69**, 417.
21. Hunten, D. M., Godson, W. L. 1967, Upper-atmospheric sodium and stratospheric warnings at high latitudes, *J. Atmos. Sci.*, **24**, 80.

22. Kendall, P. C. 1964, On the equations governing diffusion in the F2 layer, *J. atmos. terr. Phys.*, **26**, 624.

23. Kendall, P. C., Windle, D. W. 1965, A possible explanation of the Appleton anomaly of the F2-layer, I., *J. atmos. terr. Phys.*, **27**, 795 (II. 1965, *J. atmos. terr. Phys.*, **27**, 1163).

24. Mariani, F. 1964, Pitch-angle distribution of the photoelectrons and origin of the geomagnetic anomaly in the F2 layer, *J. geophys. Res.*, **69**, 556.

25. Nagata, T., Ogawa, T. 1964, Synthetic interpretation of the airglow [O I] 6300 Å emission and the ionospheric condition, *Rep. Ionosph. Space Res. Japan*, **18**, 394.

26. Peterson, V. L., Van Zandt, T. E., Norton, R. B. 1966, F-region nightglow emissions of atomic oxygen, I., *J. geophys. Res.*, **71**, 2255.

27. Peterson, V. L., Steiger, W. R. 1966, F-region nightglow emissions of atomic oxygen, II. Analysis of 6300 Å and electron density data, *J. geophys. Res.*, **71**, 2267.

28. Rishbeth, H. 1964, A time-varying model of the ionospheric F2-layer, *J. atmos. terr. Phys.*, **26**, 657.

29. Roach, F. E., Steiger, W. R., Brown, W. E. 1964, A summary of one year of observations of 6300 Å airglow at Haleakala, Tech. Rep. HIG-64-16, Hawaii Institute of Geophys.

30. Sharp, G. W. 1966, Midlatitude trough in the night ionosphere, *J. geophys. Res.*, **71**, 1345.

31. Silverman, S. M. 1965, The equatorial airglow, AFCRL-65-280.

32. Somayajulu, Y. V. 1964, Evidence on the horizontal diffusion of F-region ionization along the magnetic lines of force in equatorial latitudes, *J. geophys. Res.*, **69**, 561.

33. Somayajulu, Y. V. 1964, Some features of the F-region electron density and height variations in the equatorial regions, *J. geophys. Res.*, **69**, 1329.

34. Steiger, W. R., Brown, W. E., Roach, F. E. 1966, The alignment of 6300 Å airglow isophotes in the tropics, *J. geophys. Res.*, **71**, 2846.

35. Swider, W., Jr. 1967, On the decay of the ionospheric airglow 6300 Å line at night, Paper given at meeting of COSPAR, Vienna, 1966, *Space Res.*, **7**, in press.

36. Varnasavang, V., Hargreaves, Sylvia, Kendall, P. C. 1965, The influence of horizontal air motions on F2-region ionization, *J. atmos. terr. Phys.*, **27**, 707.

37. Yoshizaki, W. The effect of ionospheric movements on the emission rate of [O I] 6300 Å airglow, in preparation.

38. Yoshizaki, W. 1965, Binary transport of electrons and ions in the equatorial ionosphere and its effect on the brightness of [O I] 6300 Å airglow at Huancayo, *Rep. Ionosph. Space Res. Japan*, **19**, 299.

39. Pertinent paper by Soviet authors: Shefov's list, no. **23**.

### *C. Mid-latitude stable auroral arcs*

1. Bellew, W., Silverman, S. M. 1965, The dependence of occurrence of midlatitude aurora on the sunspot cycle, *J. geophys. Res.*, **70**, 4985.

2. Carleton, N. P., Roach, J. R. 1965, Spectrographic observations of a mid-latitude red auroral arc, *J. geophys. Res.*, **70**, 1262.

3. Cole, K. D. 1965, On the $D_{st}$ main phase of a magnetic storm and certain associated phenomena, in *Phys. of Geomag. Phenomena*, Ed. S. Matsushita and W. H. Campbell, Academic Press.

4. Cole, K. D. 1965, Stable auroral red arcs, sinks for energy of $D_{st}$ main phase, *J. geophys. Res.*, **70**, 1689

5. Cole, K. D. 1966, Magnetic storms and associated phenomena, *Space Sci. Rev.*, **5**, 699.

6. Cole, K. D. 1966, A magnetic storm experiment for Australia, *The Australian Physicist*, **3**, 27.

7. Cole, K. D. Suggestions for the experimental study of the stable auroral red arc and the ring current, in preparation.

8. Marovich, E. 1967, Fritz Peak observations of stable auroral arcs, *ESSA Tech. Rep.* 16.

9. Marovich, E. On the enhancement of 5577 Å emission associated with sar-arcs, in preparation.

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*D. Excitation of 6300 Å [O I] by photoelectrons*

1. Carlson, H. C., Jr. 1966, Ionospheric heating by magnetic conjugate-point photoelectrons, *J. geophys. Res.*, **71**, 195 (also paper presented to Aurora-Airglow conference at Keele, England; Reinhold, 1967, p. 643).
2. Cole, K. D. 1965, The predawn enhancement of 6300 Å airglow, *Ann. Géophys.*, **21**, 156.
3. Dalgarno, A., McElroy, M. B. 1965, Ionospheric electron temperatures near dawn, *Planet. Space Sci.*, **13**, 143.
4. Hoegy, W. R., Fournier, J.-P., Fontheim, E. G. 1965, Photoelectron energy distribution in the F-region, *J. geophys. Res.*, **70**, 5464.
5. Tohmatsu, T., Ogawa, T., Tsuruta, H. 1965, Photo-electronic processes in the upper atmosphere, I. Energy spectrum of the primary photo-electrons, *Rep. Ionosph. Space Res. Japan*, **19**, 482.

*E. Nightglow variations, temporal and spatial*

1. Barbier, D. 1965, Variations de l'intensité des principales radiations de la luminescence atmosphérique nocturne avec le cycle solaire, *Ann. Géophys.*, **21**, 265.
2. Bollinger, C. J. 1965, Comments on paper by S. H. Neff entitled 'Observation of the O I 5577 Å nightglow at Christchurch, New Zealand', *J. geophys. Res.*, **70**, 5469.
3. Chiplonkar, M. W., Agashe, V. V., Tillu, A. D. 1965, A spectrophotometric study of the night airglow at Poona, *Indian J. Pure and Applied Phys.*, **3**, 182.
4. Dandekar, B. S., Silverman, S. M. 1964, The effect of solar flares on the [O I] green line of the nightglow, *Planet. Space Sci.*, **12**, 867.
5. Dandekar, B. S. 1965, Study of the [O I] green line at Mount Abu, *J. atmos. terr. Phys.*, **27**, 245.
6. Davis, T. N., Smith, L. L. 1965, Latitudinal and seasonal variations in the night airglow, *J. geophys. Res.*, **70**, 1127.
7. Greenspan, J. A., Stone, C. A. 1965, The longitudinal variation of night airglow intensity in the region of the South Atlantic magnetic anomaly, *J. geophys. Res.*, **69**, 465.
8. Greenspan, J. A. 1966, Synoptic description of the 6300 Å nightglow near 78° west longitude, *J. atmos. terr. Phys.*, **28**, 739.
9. Hernandez, G. J. 1965, Data previous to the International Geophysical Year I: 5577 [O I] line at Sacramento Peak, New Mexico, *AFCRL*–65–319.
10. Hernandez, G. J., Silverman, S. M. 1964, A reexamination of Lord Rayleigh's data on the airglow 5577 Å [O I] emission, *Planet. Space Sci.*, **12**, 97.
11. Neff, S. H. 1965, Observations of the O I 5577 Å nightglow at Christchurch, New Zealand, *J. geophys. Res.*, **70**, 1743.
12. Okuda, M. 1965, The intensity of oxygen red line in night airglow and its dependence on solar activity, *Rep. Ionosph. Space Res. Japan*, **19**, 470.
13. Saito, B., Takahashi, T. 1966, Large amplitude variations of the intensity of oxygen 5577 Å emission in the night airglow and structure of lower thermosphere, *Rep. Ionosph. Space Res. Japan*, **20**, 439.
14. Sandford, B. P. 1964, Aurora and airglow intensity variations with time and magnetic activity at southern high latitudes, *J. atmos. terr. Phys.*, **26**, 749.
15. Silverman, S. M. 1964, A note on the diurnal variation of the 5577 Å [O I] airglow emission, *Planet. Space Sci.*, **12**, 247.
16. Silverman, S. M., Bellew, W. 1966, Magnetic storm enhancement of the 5577 Å [O I] airglow emission intensity, *Ann. Géophys.*, **22**, 458.
17. Smith, L. L., Owen, R. W. 1966, Seasonal variation of nightglow Na I 5890–96 Å, [O I] 5577 Å and [O I] 6300 Å in the tropics, *NBS Tech. Rep.* 329.
18. Pertinent papers by Soviet authors: Shefov's list, No. **17, 18, 19, 20, 21, 22, 25, 29, 30**.

*F. Hydrogen airglow*

1. Brandt, J. C. 1964, On diffuse galactic Lyman α in the night sky, *Planet. Space Sci.*, **12**, 650.
2. Donahue, T. M. 1964, Lyman alpha scattering in the Earth's hydrogen geocorona, 3. The extrageocoronal contribution, *J. geophys. Res.*, **69**, 1301.

3. Donahue, T. M. 1964, H alpha excitation in the hydrogen near the Earth. *Planet. Space Sci.*, **12**, 149.
4. Donahue, T. M. 1966, The problem of atomic hydrogen, *Ann. Géophys.*, **22**, 175.
5. Donahue, T. M., Fastie, W. G. 1964, Observation and interpretation of resonance scattering of Lyman α and O I (1300) in the upper atmosphere, *Space Res.*, **4**, 304.
6. Eather, R. H., Sandford, B. P. 1966, The zone of hydrogen emission in the night sky, *Austr. J. Phys.*, **19**, 25.
7. Kondo, Y., Kupperian, J. E. 1967, Interaction of the neutral hydrogen and charged particles in the radiation belt: the consequent Lyman alpha emission, in preparation (to be submitted to *J. geophys. Res.*).
8. Winter, T. C. 1965, The determination of the profile of the north-south hydrogen Lyman alpha emission line, Ph.D. dissertation, UCLA.
9. Pertinent papers by Soviet authors: Shefov's list, no. **31, 32, 33, 34, 35, 36, 37**.

### *G. Aeronomy and excitation processes*

1. Barbier, D. 1964, Possibilité de détection de particules de grande énergie dans la haute atmosphère par des observations de la luminescence nocturne atmosphérique, *Space Res.*, **5**, Proc. 5th int. Space Sci. Sym., Florence, 8–20 May, 1964.
2. Barth, C. A. 1964, Three body reactions, *Ann. Géophys.*, **20**, 182.
3. Barth, C. A. 1966, Nitric Oxide in the upper atmosphere, *Ann. Géophys.*, **22**, 198.
4. Bates, D. R. 1964, Chemical reactions contributing to the nightglow, *Discussions of the Faraday Society*, No. 37, 21.
5. Batey, P. H., Court, G. R., Sayers, J. 1965, Afterglow measurements of the rate coefficients for the reactions $O^+ + O_2 \rightarrow O_2^+ + O$ and $O^+ + N_2 \rightarrow NO^+ + N$, *Planet. Space Sci.*, **13**, 911.
6. Dalgarno, A. 1964, Corpuscular radiation in the upper atmosphere, *Ann. Géophys.*, **20**, 65.
7. DeMore, W. B., Raper, O. F. 1964, Deactivation of $O(^1D)$ in the atmosphere, *Astrophys. J.*, **139**, 1381.
8. Desesquelles, J., Do Cao, G., Dufay, M. 1966, Etude de l'ionization de quelques gas par des ions accélérés $H_2^+$, *C. r. Acad. Sci.*, Paris, **262**, 1329.
9. Donahue, T. M. 1966, Ionospheric reaction rates in the light of recent measurements in the ionosphere and the laboratory, *Planet. Space Sci.*, **14**, 33.
10. Donahue, T. M. 1967, The sodium airglow, *International Dictionary of Geophysics*, Pergamon.
11. Dufay, M., Druetta, M., Eidelsberg, M. 1965, Sur la luminescence de l'oxygène excitée par choc de particules accélérées sous 500 keV, *C. r. Acad. Sci.*, Paris, **260**, 1123.
12. Dufay, M., Druetta, M., Eidelsburg, M. 1965, Sur l'excitation de l'azote et de l'oxygène par ions accélérés, *C. r. Acad. Sci.*, Paris, **261**, 1635.
13. Dufay, M., Druetta, M., Eidelsberg, M. 1965, Sur la luminescence de l'azote excitée par choc de particules accélérées sous 500 keV, *C. r. Acad. Sci.*, Paris, **260**, 1901.
14. Dufay, M., Desesquelles, J., Druetta, M., Eidelsberg, M. Relatif à l'ensemble des expériences sur l'excitation des spectres de l'oxgène et de l'azote, *Ann. Géophys.*, in press.
15. Fehsenfeld, F. C., Schmeltekopf, A. L., Ferguson, E. E. 1965, Some measured rates for oxygen and nitrogen ion-molecule reactions at atmospheric importance, including $O^+ + N_2 \rightarrow NO^+ + N$, *Planet. Space Sci.*, **13**, 219.
16. Fehsenfeld, F. C., Goldan, P. D., Schmeltekopf, A. L., Ferguson, E. E. 1965, Laboratory measurement of the rate of the reaction $O^+ + O_2 \rightarrow O_2^+ + O$ at thermal energy, *Planet. Space Sci.*, **13**, 579.
17. Fite, W. L. 1964, Charge transfer and ion-atom interchange collisions above thermal energies, *Ann. Géophys.*, **20**, 47.
18. Hunten, D. M., McElroy, M. B. 1966, Quenching of metastable states of atomic and molecular oxygen and nitrogen, *Rev. Geophys.*, **4**, 303.
19. Megill, L. R., Carleton, N. P. 1964, Excitation by local electric fields in the aurora and airglow, *J. geophys. Res.*, **69**, 101.

https://doi.org/10.1017/S0251107X00030509 Published online by Cambridge University Press

**20.** Megill, L. R., Cahn, J. H. 1964, The calculation of electron energy distribution functions in the ionosphere, *J. geophys. Res.*, **69,** 5041.
**21.** Nathan, K. V. S. K. 1966, Particle heating effects in the upper F-region, *Planet. Space Sci.*, **14,** 717.
**22.** Nichols, R. W. 1964, Transition probabilities of aeromically important spectra, *Ann. Géophys.*, **20,** 144.
**23.** Ogawa, T., Tohmatsu, T. 1966, Photoelectronic processes in the upper atmosphere, II. The hydrogen and helium ultraviolet glow as an origin of the night-time ionosphere, *Rep. Ionosph. Space Res. Japan*, **20,** 395.
**24.** Paulson, J. F. 1964, Low energy charge exchange and ion-molecule reactions, *Ann. Géophys.*, **20,** 75.
**25.** Poulizac, M.-C., Desesquelles, J., Dufay, M. Sur l'excitation de l'oxyde de carbone par chocs protoniques, *C. r. Acad. Sci.*, Paris, in press.
**26.** Prag, A. B., Morse, Fred A., McNeal, R. J. 1966, Nightglow excitation and maintenance of the nighttime ionosphere by low-energy protons, *J. geophys. Res.*, **71,** 3141.
**27.** Schiff, H. I., Megill, L. R. 1964, The influence of metastable oxygen molecules on ozone and airglow, *J. geophys. Res.*, **69,** 5120.
**28.** Swider, W., Jr. 1965, A study of the nighttime ionosphere and its reaction rates, *J. geophys. Res.*, **70,** 4859.
**29.** Thomas, L., Norton, R. B. 1966, Possible importance of internal excitation in ion-molecule reactions in the F-region, *J. geophys. Res.*, **71,** 227.
**30.** Young, R. A., Black, G. 1966, Excitation of the auroral green line in the Earth's nightglow, *Planet. Space Sci.*, **14,** 113.
**31.** Pertinent papers by Soviet authors: Shefov's list, no. **43, 44, 45, 46.**

### *H. $N_2^+$ in the nightglow*

**1.** Broadfoot, L., Hunten, D. M. 1966, $N_2^+$ emission in twilight, *Planet. Space Sci.*, **14,** 1303.
**2.** Dalgarno, A., Latimer, I. D., McConkey, J. W. 1965, Corpuscular bombardment and $N_2^+$ radiation, *Planet. Space Sci.*, **13,** 1008.
**3.** Dalgarno, A., McElroy, M. B. 1966, Twilight effects of solar ionizing radiation, *Planet. Space Sci.*, **14,** 1321.
**4.** O'Brien, B. J., Allum, F. R., Goldwire, H. C. 1965, Rocket measurement of midlatitude airglow and particle precipitation, *J. geophys. Res.*, **70,** 161.
**5.** Yano, Kyo 1966, $N_2^+$ ions in the nocturnal upper atmosphere at middle latitudes, *Planet. Space Sci.*, **14,** 709.

### *I. Hydroxyl (OH) Nightglow*

**1.** Huruhata, M. 1965, Correlation between the OH radiation in the night airglow and the height of the 10-millibar surface, *J. geophys. Res.*, **70,** 4927.
**2.** Nguyen, Huu-Doan 1963, Temperature de rotation des bandes (9–3) et (6–1) de la molecule OH, *C. r. Acad. Sci.*, Paris, **256,** 245.
**3.** Noxon, J. F. 1964, The latitude dependence of OH rotational temperature in the night airglow, *J. geophys. Res.*, **69,** 4087.
**4.** Stair, A. T. Jr., Kennealy, J. P., Stewart, S. P. 1965, Observation of the $\Delta v = 1$ sequence of OH produced in the H + $O_3$ reaction, *Planet. Space Sci.*, **13,** 1005.
**5.** Wolstencroft, R. D., Brandt, J. C., Rose, L. J. 1966, Anomalous brightness of the post-twilight evening sky in the near infra-red, *Planet. Space Sci.*, **14,** 445.
**6.** Pertinent papers by Soviet authors: Shefov's list, no. **1, 2, 3, 4, 6, 8, 9, 10, 11, 12, 14.**

### *J. Doppler temperatures*

**1.** Fymat, A. L., Venketeswaran, S. V. 1965, The Doppler temperatures obtained from the 6300 Å line of atomic oxygen in the airglow, *Ann. Géophys.*, **21,** 443.
**2.** Hernandez, G. J., Turtte, J. P. 1965, Nightglow 5577 Å [O I] line kinetic temperatures, *Planet. Space Sci.*, **13,** 901.

3. Hilliard, R. L., Shepherd, G. G. 1966, Upper atmospheric temperatures from Doppler line widths, IV. A detailed study using the [O I] 5577 Å auroral and nightglow emission, *Planet. Space Sci.*, **14,** 383.
4. Jarrett, A. H., Hoey, M. J., Paffrath, L. 1964, Observations of the 6300 Å O I emission of the nightglow with a pressure scanning Fabry-Perot interferometer, *Planet. Space Sci.*, **12,** 591.
5. Jarrett, A. H., Hoey, M. J. 1965, Temperature determinations of the Earth's upper atmosphere by optical methods, *Proc. R. Soc. London*, Ser. A **288,** 510.
6. Jarrett, A. H., Hoey, M. J. 1966, Observations of the 6300 Å O I nightglow emission, *J. atmos. terr. Phys.*, **28,** 175.

## *K. Instrumentation and techniques*

1. Best, G. T. 1965, A new use of the van Rhijn formula for airglow measurements, *Planet. Space Sci.*, **13,** 855.
2. Blacker, H. V., Gadsden, M. 1966, On the calibration of airglow photometers, *Planet. Space Sci.*, **14,** 921.
3. Chiplonkar, M. W., Agashe, V. V., Tillu, A. D. 1966, Heights of the airglow emission layers at Poona, *Indian J. Meteorology Geophys.*, **17,** 95.
4. Dumont, R. 1965, Séparation des composantes atmosphérique, interplanétaire et stellaire du ciel nocturne à 5000 Å A. Application à la photométrie de la lumière zodiacale et du gegenschein, *Ann. Astrophys.*, **28,** 265.
5. Kulkarni, P. V., Sanders, C. L. 1964, Use of a radioactivated light source for the absolute calibration of two-colour night airglow photometer, *Planet. Space Sci.*, **12,** 189.
6. Wolff, M. M. 1966, A new attack on height measurement of the nightglow by ground triangulation, *J. geophys. Res.*, **71,** 2743.
7. Wolff, M. M., Garmil, J. Summary: Measurements have been made of the height of the 5577 Å nightglow layer using a new method of ground-based triangulation. The theory of the method is discussed and results compared with other methods. Average height obtained was 97 ± 3 kilometers, in preparation.
8. Pertinent papers by Soviet authors: Shefov's list, no. **26, 28.**

## *L. Rocket and satellite observations*

1. Gillett, F. C., Huch, W. F., Ney, E. P., Cooper, G. 1964, Photographic observations of the airglow layer, *J. geophys. Res.*, **69,** 2827.
2. Gulledge, I. S., Packer, D. M., Tilford, S. G. 1966, Rocket measurements of the high altitude [O I] 5577 Å and 6300 Å night airglow, *Trans. Am. geophys. Un.*, **47,** 74.
3. Hennes, J. P. 1966, Measurement of the ultraviolet nightglow spectrum, *J. geophys. Res.*, **71,** 763.
4. Hennes, J. P., Dunkelman, L. 1966, Photographic observations of nightglow from rockets, *J. geophys. Res.*, **71,** 755.
5. Huruhata, M., Nakamura, T., Tanabe, H. 1966, Rocket observations of emitting height of 6300 Å oxygen line in night airglow, *Rep. Ionosph. Space Res. Japan*, **20,** 223.
6. NASA. Results of the first U.S. manned orbital space flight (20 February 1962).
   Appendix C, pp. 195–198, Description of the MA–6 Astronomical, Meteorological and Terrestrial Observations by John H. Glenn, Jr.
   Appendix D, pp. 199–204, Preliminary report on the results of the MA–6 flight in the field of space science by John A. O'Keefe.
7. NASA SP–6. Results of the second U.S. manned orbital space flight (24 May 1962).
   Chapter 4, pp. 35–42, Space Science Report by John A. O'Keefe.
   Chapter 7, pp. 69–75, Pilot's flight report by M. Scott Carpenter.
8. NASA SP–12. Results of the third U.S. manned orbital space flight (3 October 1962).
   Chapter 4, pp. 37–48, Pilot's flight report by Walter M. Schirra, Jr.

9. NASA SP–45. Mercury project summary including results of the fourth manned orbital flight (15–16 May 1963).
Chapter 19, pp. 327–347, Observations of space phenomena by John A. O'Keefe, L. Dunkelman, S. D. Soules and P. D. Lowman, Jr.
Chapter 20, pp. 349–358, Astronaut's summary flight report by L. Gordon Cooper.
10. NASA. Manned Space Flight Experiments Symposium, Gemini Missions 3 and 4 (18–19 October 1965).
Chapter 1, pp. 1–18, Geo-astronomical observations by L. Dunkelman, J. R. Gill, J. A. McDivitt, F. E. Roach, and E. H. White II.
Gemini 3 –
Gemini 4 – 3–7 June 1965.
11. NASA SP–121. Gemini Midprogram Conference (23–25 February 1966).
(32) Geoastronomical observations, pp. 315–323, by F. E. Roach, L. Dunkelman, J. R. Gill, R. D. Mercer.
(33) Dim light photography, pp. 325–328, by L. Dunkelman, and R. D. Mercer.
12. NASA report dated 1 November 1966.
Interim report, Gemini 9 mission.
Experiment S–1 Zodiacal light photography by E. P. Ney and W. F. Huch, pp. 1–6.
Experiment S–11 Airglow horizon photography by M. J. Koomen and R. T. Seal, Jr.
13. O'Brien, B. J., Allum, F. R., Goldwire, H. C. 1965, Rocket measurements of midlatitude airglow and particle precipitation, *J. geophys. Res.*, **70**, 161.
14. Reed, E. I., Blamont, J. R. 1966, Some results concerning the principal airglow lines as measured from the OGO–II satellite, *NASA* X–613–66–190.
15. Stecher, Th. P. 1965, The spectral energy distribution of the Earth's ultraviolet night airglow, *J. geophys. Res.*, **70**, 2209.

### *M. Twilight glow*

1. Gadsden, M. 1967, Twilight observations (Review paper with 22 references to papers in this field since 1964), *Aurora and Airglow*, Reinhold, p. 109.
2. Hunten, D. M. 1967, Spectroscopic studies of the twilight airglow (Review paper with 60 references to papers in this field and dayglow since 1964), *Space Sci. Rev.*, **6**, 493.
3. Pertinent papers by Soviet authors: Shefov's list, no. **38, 39, 40, 41, 42, 43.**

## APPENDIX I. SPECTRAL INVESTIGATIONS OF THE UPPER ATMOSPHERE EMISSIONS IN THE U.S.S.R.

(prepared by N. N. Shefov)

During a period following the IGY and during the IQSY period in the Soviet Union systematic investigations were continued into the properties of the upper atmosphere emissions by means of spectrographic and photoelectric methods. The data obtained for several years at Abastumani have shown that during a period since 1953 the average annual intensity of hydroxyl emission had a maximum in 1958. After a small minimum in 1961–62 the intensity began to increase again (**1**). The study of the seasonal variations of the intensity and rotational temperatures of the OH bands has revealed long ago that there is a maximum in the winter months and a minimum in the summer months. This result has been confirmed by observations lasting many years at many stations (**1–3**). The amplitude of the seasonal variations of the rotational temperature is greater for bands from higher initial vibrational levels.

Statistical processing of the data on OH emission obtained for a number of years has made it possible to reveal periodic variations of mean diurnal intensities and rotational temperatures of OH bands (4, 1), (5, 2), (6, 2) and (7, 3) with periods of 27 days and 29·5 days (the age of the Moon) from observations at Zvenigorod (**2**) and the OH band (9, 3) with a period of 27 days by observations at Yakutsk (**4–6**). 27-day variations in the intensity and rotational temperature of OH bands (4, 1), (5, 2) and (9, 3) take place in antiphase and OH bands (6, 2) and (7, 3)

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synchronously. According to the data obtained at Yakutsk, along with the 27-day variations in the rotational temperature of the OH band (9, 3), 27-day variations in the atmospheric temperature were also observed at a level of 50 mb and the height of the isobaric surface of 15 mb (~ 27–28 km).

The variations in the rotational temperature of OH bands (4, 1), (5, 2), (6, 2) and (7, 3) with the Moon's age have their deepest minimum during the full Moon and the least during the new Moon and two maxima in the first and the last quarters. Variations in the intensity of OH bands (6, 2) and (7, 3) are similar. For OH bands (4, 1) and (5, 2) there are almost no intensity variations with the Moon's age.

Studies of the behaviour of the intensity and rotational temperature of OH bands in the presence of noctilucent clouds have shown that the intensity of OH emission, as well as of the atmospheric band (0, 1) $O_2$ grows during a period of the appearance of noctilucent clouds and sharply decreases the following night (up to 2–3 times with respect of the mean intensity), when noctilucent clouds are already absent. The following night the intensities of OH and $O_2$ emissions are restored to their mean values. Such a regularity has been observed annually since 1962 (**7–9**). The rotational temperature of OH bands varies little, although it reaches the values of 160–180°K during the period of the emergence of noctilucent clouds. This seems to be accounted for by the fact that the rotational temperature variations reflect changes in the height of rather a wide emitting layer.

The clarification of the character of dirunal variations of OH emission has shown that there are diverse types of variations in intensity and rotational temperature of different bands (**1, 10, 11**). However, most often variations of the same phase of mean values of the intensity and rotational temperatures are observed. Against the background of such variations, fluctuations can take place. Periodic variations of the rotational temperature of OH bands have been revealed with a period of about 1 hour and the modulation depth of 30–40° (**10**). Such variations are observed mainly early at night. During the evening twilight (at the solar depression angle from 7 to 18°) the OH band intensity decreases by 30% on the average. The rotational temperature decreases on the average by 15°. On the average during the morning twilight the intensity and the rotational temperature is lower than in the evening (**12**). From observations in high latitudes no correlation has been observed between variations in the intensity and OH rotational temperature and auroral displays (**11**).

The study of spatial irregularities of OH emission by the data of different stations has shown that co-phaseness and simultaneity of rotational temperature variations have been systematically observed at distances of up to 3000 km (**3, 11**). The patchy structure of the intensity and rotational temperature which was already supposed (**13**) has been revealed from observations at Anastumani (**1**) and Zvenigorod (**10**). A comparison of simultaneous diurnal temperature variations at different points of the sky has provided an opportunity of estimating the velocity of the vertical wind – 1 to 3 m $s^{-1}$ and the horizontal east-west wind – 30 to 200 m $s^{-1}$ (**10**).

Investigations of the dependence between the intensities of OH bands (3, 0), (4, 1), (5, 2), (6, 2), (7, 3), (8, 4), (9, 5) and $O_2$ (0, 1) revealed earlier have made it possible to find two types of correlations between them (**14**). With the intensity of oxygen emission of less than 0·3–0·5 kilorayleighs the correlation field has the form of a sector (**15**). The intensities of OH bands can reach maximum observed values.

With the oxygen emission intensities of over 0·5 kilorayleighs, the correlation becomes linear rather rapidly up to the maximum observed values of intensities. These data permit one to over the vertical distribution of OH and $O_2$ emissions.

A great amount of data on spatial and time variations of green and red emissions of atomic oxygen has been obtained in Ashkhabad. Maps of isophotes obtained from observations in

1964 have been published (**16**). The time of the existence of emission patches can vary from a few minutes to a few hours (**17**). The size of patches and their intensities can often pulsate. Periods of 5·5 and 15·5 minutes have been observed. The most typical size of patches is 60–90 km. The minimum size is about 30 km. The distribution of the velocities of the patches has two maxima—about 75 m $s^{-1}$ and 150 m $s^{-1}$. The velocity of patches increases with the increase of the *K*-index (**18–20**). The greatest velocity of motion is observed in October. A dependence of the intensity of the emission of 5577 Å on lunar time has been revealed. The amplitude of variations is 35 rayleighs and the intensity minimum coincides with the moment of the Moon's lower culmination (**19**). A comparison of the data of observations of red and green emissions has shown the existence of patches of emissions of 6300 Å (situated at a height of 400 km) and of 5577 Å (at a height of 100 km) lying at the same geomagnetic line of force (**17, 21, 22**). In this case small rise is observed in the region of 3914 Å. If the intensity of this additional emission is due to the emission of $N_2^+$ of 3914 Å, its maximum intensity is not more than 10 rayleighs (**23**).

Investigations of the properties of the continuum of the spectrum of the nightglow have led to the detection of spatial and time variations of both the intensity and spectral distribution of the continuum (**24–27**). Therefore observations of emissions with wide filters at a constant point of the sky do not allow one to determine correctly the intensities of discrete lines (**28**). Sodium emission in the night sky also has a patchy structure. The velocities of the motion of patches are about 70 m $s^{-1}$. The motion is mainly eastward and northward (**29**).

As a result of the hydrogen emission observations of many years at Abastumani, data have been obtained on variations of the H$\alpha$ emission intensity during a solar cycle. In the years of a minimum (1962) its mean yearly intensity was maximum (**30, 31**) and constituted about 20 rayleighs. Such a character of variations gives evidence for the terrestrial origin of H$\alpha$ emission. Observations of hydrogen emission have made it possible to calculate hydrogen distribution in the atmosphere (**31, 32**) supposing the fluorescence mechanism of solar radiation in the $L\beta$ line. Observations performed by means of the Fabry-Perot interferometer (**33–37**) confirmed the minimum detected earlier at the antisolar point. The width of the H$\alpha$ line does not exceed 0·3 Å while in emission nebulae the emission line width sometimes exceeds this value. The existence of variations in the Celestial Pole speaks in favour of the emergence of the emission in the Earth's atmosphere. It has been revealed that H$\alpha$ emission is concentrated in the ecliptic. The intensity on the morning side exceeds several times the H$\alpha$ intensity on the evening side of the Earth. Radial velocities with the elongation of 30° do not exceed the instrumental limit of 4·5 km $s^{-1}$.

Investigations of helium emission of the upper atmosphere have been carried out for several years using spectrographic and photoelectric methods. Variations have been obtained of the intensity of helium emission and the calculated flux of solar ultraviolet radiation (**37, 38**). According to the data of photographic observations at Zvenigorod it turns out that on the average the helium emission intensity for the *K*-index $< 4$ remains almost constant and only with the *K*-index $> 4$ a sharp increase in the intensity begins. For the local *K*-index this transition takes place more sharply than for the planetary one. According to observations in high latitudes, the helium emission intensity very often reached several kilorayleighs (**39**). Variations of the helium emission intensity in ordinary twilight have a noticeable evening-morning asymmetry which gave the opportunity to determine the atmospheric temperature, which in the morning turns out to be lower than in the evening (**40**). The calculation has been performed on the basis of the theory of excitation of metastable helium atoms by photoelectrons and fluorescence of these atoms in solar radiation (**41–44**). The evening-morning intensity asymmetry was detected also from observations in high latitudes (**39**).

The estimate of intensities of argon and neon emissions in the upper atmosphere turned out to be very low even in auroras (**45**). However, the existence of argon and neon metastable atoms

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in the atmosphere can be revealed in ordinary auroras from the properties of variations in the atomic oxygen line of 8446Å (**46**).

An analysis was made of auroral spectra observed at various stations during several years. The relative and absolute intensities for many auroras have been obtained (**47–49**). The height distribution of intensities of emission of $N^+$, 5577Å, 6300Å, 1 PG $N_2$ in auroras varies in different auroral forms (**50, 51**). A correlation is observed between height distributions of emissions of 5577Å, 1 PG $N_2^+$ and 1 NG $O_2^+$. However, the relationship between them depends on the form of auroras. The properties and specific features of an aurora of 10–11 February 1958 have been time and again discussed in several papers (**44, 52–55**). The ratios of the intensities of nebular and auroral transitions for oxygen and nitrogen atoms and ions have been studied. The energy released in auroras reach 10–100 erg $cm^{-2} s^{-1}$.

On the basis of auroral hydrogen line contours obtained at different zenithal distances a distribution of injected protons by pitch-angles has been calculated as well as the energy spectrum which well agrees with the measured spectrum in the solar wind (**56**).

On determinations of the heights of night sky emissions it was reported in (**57, 58**).

## *References*

*Sbornik* in the references is for 'Aurorae and Airglow', series 'Results of IGY', Publishing House NAUKA of the U.S.S.R. Academy of Sciences. Letters refer to general bibliography, above, pages 415 to 422.


1. (I) Fishkova, L. M., Marzvaladze, N. M. 1966, Some results of the upper atmosphere hydroxyl emission according to the observations in Abastumani. *Sbornik*, no. 13, 24.
2. (I) Shefov, N. N. 1966, Some properties of the hydroxyl emission. *Sbornik*, no. 13, 21.
3. (I) Sidorov, V. N. Some results of the observations of the hydroxyl emission during IQSY. *Sbornik*, no. 18, in press.
4. (I) Kuzmin, A. I., Krivoshapkin, P. A., Chirkov, N. P., Yarin, V. I. 1963, Investigations of the atmospheric temperature above Yakutsk. Report to the XIIIth IQSY Assemblee, Berkeley.
5. Kuzmin, A. I. 1964, Variations of the high energy cosmic rays. Publishing House, 'NAUKA', Moscow.
6. (I) Yarin, V. I. Connection of the hydroxyl emission with the meteorological conditions above Yakutsk. *Sbornik*, no. 18, in press.
7. (A) Shefov, N. N. 1965, The upper atmosphere emissions and the noctilucent clouds. *Sbornik*, no. 11, 48.
8. (I) Shefov, N. N. 1966, OH emission and noctilucent clouds. Proc. Intern. Conference on Noctilucent Clouds, Tallin.
9. (I) Shefov, N. N. OH variations during the occurrences of the noctilucent clouds. *Sbornik*, no. 18, in press.
10. (I) Taranova, O. G. 1966, Studies of the spatial and temporal properties of the hydroxyl emission. *Sbornik*, no. 13, 10.
11. (I) Fedorova, N. I. 1966, Hydroxyl emission at the high latitudes. *Sbornik*, no. 13, 14.
12. (I) Taranova, O. G., Toroshelidze, T. I. On the measurements of the hydroxyl emission in twilight. *Sbornik*, no. 18, in press.
13. (A) Krassovsky, V. I., Shefov, N. N. 1965, Airglow. *Space Sci. Rev.*, **4**, 176.
14. (I) Taranova, O. G. Connection between the hydroxyl and molecular oxygen emissions. *Sbornik*, no. 18, in press.
15. (A) Shefov, N. N. 1965, Correlations between the upper atmosphere emissions. *Sbornik*, no. 11, 43.
16. (A) Korobeynikova, M. P., Nasirov, G. A., Khamidulina, V. G. 1966, The nightglow emission $\lambda$ 5577Å. Tables and isophote maps. Serie 'Results of IQSY', Publishing House VINITI, Moscow.

17. (E) Truttse, Yu. L. 1965, The spatial variations of the oxygen lines intensities. *Sbornik*, no. 11, 52.

18. (E) Nasirov, G. A. 1966, The peculiarities of the spatial pattern structure of the atomic oxygen emission λ5577Å in the nightglow. *Sbornik*, no. 13, 5.

19. (E) Korobeynikova, M. P., Nasirov, G. A., Khamidulina, V. G. Intensity variations and dynamical characteristics of the spatial patches of the emission λ5577Å. *Sbornik*, no. 18, in press.

20. (E) Kalchaev, K. K., Korobeynikova, M. P., Nasirov, G. A., Khamidulina, V. G. Search of the rapid spatial variations of the intensity of the oxygen green line. *Sbornik*, no. 18, in press.

21. (E) Truttse, Yu. L. 1963, Connection between the pattern structures of the green and red emissions of the atomic oxygen in the nightglow. *Astr. Cirk.*, U.S.S.R., no. 258, 1.

22. (E) Truttse, Yu. L. 1964, Connection between green and red oxygen emission patches. *Planet. Space Sci.*, **12,** 725.

23. (B) Krassovsky, V. I., Truttse, Yu. L., Shefov, N. N. 1965, On the mechanism of maintenance of the nocturnal ionosphere. *Space Res.*, **5,** North-Holland Publishing Company, Amsterdam, 43–48.

24. (A) Nasirov, G. A. 1964, On the continuum in the nightglow. *Geomag. Aeronom.*, U.S.S.R., **4,** 1118.

25. (E) Truttse, Yu. L. 1965, The spectral variations of the nightglow continuum. *Sbornik*, no. 11, 6.

26. (K) Migulin, A. V. 1965, On the separation of the nightglow continuum components. *Sbornik*, no. 11, 20.

27. (A) Gindilis, L. M. 1965, The absolute measurements of the nightglow continuum. *Sbornik*, no. 11, 26.

28. (K) Taranova, O. G. 1965, On the statistical treatment of the photoelectric measurements with the filters. *Sbornik*, no. 11, 35.

29. (E) Nasirov, G. A. 1966, Spatial variations of the nightglow in the region λ5893Å. *Sbornik*, no. 13, 8.

30. (E) Fishkova, L. M. 1962, Intensity variations and spatial distribution of the λ6563Å emission. *Abastumansk. astrofiz. Obs. Bjull.*, no. 29, 77.

31. (F) Fishkova, L. M., Marzvaladze, N. M. 1966. On the Hα-emission variations and on the hydrogen distribution in the upper atmosphere and geocorona. *Sbornik*, no. 13, 38.

32. (F) Fishkova, L. M., Marzvaladze, N. M. 1963, On the hydrogen distribution in the upper atmosphere and geocorona. *Astr. Cirk.*, U.S.S.R., no. 253, 1.

33. (F) Shcheglov, P. V. 1963, On the concentration of nightglow Hα-emission to the ecliptic and the radial velocities of this line. *Astr. Cirk.*, U.S.S.R., no. 237, 1.

34. (F) Shcheglov, P. V. 1963, Concentration of nightglow Hα-emission to the ecliptic and the radial velocities of this line. *Nature*, **199,** 990.

35. (F) Shcheglov, P. V. 1963, The flat hydrogen cloud around the Earth. *Priroda*, Moskva, no. 8, 85.

36. (F) Shcheglov, P. V. 1964, Concentration of nightglow Hα-emission to the ecliptic and the radial velocities of this line. *Astr. Zu.*, **41,** 371.

37. (F) Krassovsky, V. I., Shefov, N. N., Vaisberg, O. L. 1966, Atomic hydrogen and helium in the airglow. *Ann. Géophys.*, **22,** 208.

38. (M) Shefov, N. N. 1966, Statistical properties of the helium emission. *Sbornik*, no. 13, 35.

39. (M) Fedorova, N. I. 1966, The twilight helium emission at the high latitudes. *Sbornik*, no. 13, 30.

40. (M) Taranova, O. G. 1966, On the diurnal variations of the helium emission. *Sbornik*, no. 13, 27.

41. (M) Shefov, N. N. 1963, Helium in the upper atmosphere. *Planet. Space Sci.*, **10,** 73.

42. (M) Shefov, N. N. 1963, The behaviour of the helium λ10830Å emission in twilight. *Sbornik*, no. 10, 56.

43. (G) Krassovsky, V. I., Shefov, N. N. 1964, Fast photoelectrons and helium emission in the upper atmosphere. *Planet. Space Sci.*, **12,** 91.

https://doi.org/10.1017/S0251107X00030509 Published online by Cambridge University Press

44. (G) Krassovsky, V. I., Shefov, N. N. 1965, On the mechanism of production of metastable orthohelium atoms in the upper atmosphere. *Space Res.*, **5**, North-Holland Publishing Company, Amsterdam, 822-825.
45. (G) Shefov, N. N. 1965, The rare gas emissions in the airglow and aurora. *Sbornik*, no. 11, 65.
46. (G) Galperin, Yu. I., Sobelman, I. I. 1965, On the possible role of the metastable states of argon and neon in the auroral afterglow processes. *Geomagn. Aeronom.*, U.S.S.R., **5**, 729.
47. (N) Yashchenko, I. A. 1965, The relative intensities of the auroral emissions in the visual spectrum. *Sbornik*, no. 11, 70.
48. (N) Shouyskaya, F. K. 1966, Relative populations of the upper vibrational levels in the 2 PG $N_2$ bands in the aurorae at different latitudes. *Sbornik*, no. 13, 48.
49. (N) Yurchenko, O. T. Absolute intensities of aurorae in Zvenigorod. *Sbornik*, no. 18, in press.
50. (N) Vaisberg, O. L., Shuyskaya, F. K. 1964, Ions $N_2^+$ density in the high rays in aurora. *Geomagn. Aeronom.*, U.S.S.R., **4**, 785.
51. (N) Fedorova, N. I. Emission height distributions in the low auroral form at the high latitudes. *Sbornik*, no. 18, in press.
52. (N) Krassovsky, V. I. 1964, Polar auroras. *Space Sci. Rev.*, **3**, 232.
53. (N) Krassovsky, V. I. 1965, Problems relating to the power of aurorae. *Space Res.*, **5**, North-Holland Publishing Company, Amsterdam, 71–76.
54. (N) Shouyskaya, F. K. 1966, Observations of the aurora on 11 February 1958 at Roshchino, Leningrad. *Sbornik*, no. 13, 51.
55. (N) Shefov, N. N. Spectral properties of the aurora on 11 February 1958. *Sbornik*, no. 18, in press.
56. (N) Vaisberg, O. L. 1966, Pitch-angle and energy proton distribution in the aurorae. *Sbornik*, no. 13, 42.
57. (A) Tarasova, T. M., Slepova, V. A. 1964, Intensity height distribution of the principal emission of the nightglow. *Geomagn. Aeronom.*, U.S.S.R., **4**, 321.
58. (A) Tarasova, T. M. 1966, Nightglow in the region λ6300 Å. *Kosmičeskie Issledovanja*, **4**, no. 2, 242–248.