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THE NIGHT-SKY EMISSION SPECTRUM IN THE RANGE 3100-7700 Å OBTAINED WITH THE MODERATE RESOLUTION ECHELLE SPECTROMETER OF THE 6 M TELESCOPE

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ABSTRACT. *A night-sky emission spectrum obtained on the echelle spectrograph of the 6 m telescope with a resolution of 1.5-2 Å is presented. The technique of data reduction is briefly described, spectral details in the wavelength range 3100-7700 Å are identified, the results are compared with the data of other authors.*

1. INTRODUCTION

The use of the echelle spectrograph "Zebra" on the 6 m telescope has demonstrated that it holds much promise for the problems of stellar and extragalactic spectroscopy, which require spectral resolution no worse than 1.5-2 Å. Possessing such a resolution and capability of simultaneous registration of the object spectra in the entire optical range, good transmission of the optics in the ultraviolet region of the spectrum, this spectrograph has advantages as compared to other spectral apparature used on the 6 m telescope for investigation of objects fainter than $12\text{-}13^m$.

Spectral study of objects with the echelle spectrograph shows that the night-sky radiation gives a considerable contribution in the form of emission lines in the red and ultraviolet parts of the spectrum. To allow for this contribution, which is especially important for objects fainter than $14\text{-}15^m$, it is necessary to have accurate information on the wavelengths of spectral features, their relative intensities and variability. This is vital because it is impossible to accumulate the object and night-sky spectra at one and the same time, the sky spectrum must be registered before or after the object exposure. It is natural that accurate data on the wavelengths of the night-sky spectrum details allow also to control independently the quality of dispersion curve construction and, finally, radial velocity measurements in the spectrum.

It should be noted that among numerous papers which consider the night-sky radiation spectrum there is no research that would comply completely with the requirements of operation with the echelle spectrograph. So, the well known atlas (Krasovsky et al., 1962) contains the night-sky radiation spectrum taken with insufficiently high resolution. The investigations made with the acceptable dispersion cover only separate regions of the spectrum (Worker, 1971; Louistisserand, et al., 1987; Chamberliain and Roesler, 1955; Ingham, 1962a, 1962b).

The purpose of our work is identification of the night-sky spectrum throughout the whole optical range, comparison of these data with the results of other authors, and compilation of atlas of the night-sky spectrum fit to be used in reduction of spectral data obtained with a moderate resolution.

2. OBSERVATIONS AND DATA PROCESSING

The spectral data were taken on October 16/17, 1990 in the process of spectral investigation of faint stars in globular clusters and extragalactic objects using the echelle spectrometer of the 6 m telescope. These data were used for the account of the effect of the night-sky radiation on data obtained. The total time of the night-sky spectrum acquisition was about 1.5 hours, which permitted to investigate rather faint and numerous spectral details. The observations were made in the moonless period, which allowed to consider the obtained spectrum typical of the night-sky radiation in the absence of the Moon. For the calibration of the wavelength scale a calibration spectrum of an argon-filled lamp was taken at the beginning of the night, and the spectrum of the standard star Feige 34 accumulated at the end of the observations made it possible to reduce the whole spectrum to a unified scale of relative energetic units.

A detailed description of the data reduction technique has been presented in the paper by Vlasyuk (1993). Therefore let us dwell briefly on the specific moments of reduction of the given spectrum. As pointed out in the paper mentioned above, the instabilities of the registration system are defined first of all by the effect of the terrestrial magnetic field, therefore to derive the accurate wavelength scale, it is necessary to obtain the acquisition of the comparison spectrum before or after the spectrum under investigation, which is not always possible because of the time losses. By the way, we propose in this paper a more efficient way of achieving reliable calibration of spectra.

In our case only one reference spectrum was available taken at the beginning of the night, therefore we had to correct the obtained scale with the account of the measured known lines in the spectrum. The mean-square error of the dispersion curve plotting did not exceed 0.2 Å in the red region of the spectrum, where the reciprocal linear dispersion was 1-1.3 Å/element and 0.15 Å in the blue (λλ>3800 Å), where it was 0.6-0.8 Å/element. The deviations of the measured wavelengths for the known lines after correction were no less than 0.3-0.4 Å.

To define the accurate wavelength scale in the ultraviolet region of the spectrum (λλ<3800 Å), where the lines of the comparison spectrum are absent, first we had to construct a rough scale by extrapolation of the dispersion curve coefficients obtained in other orders, and then, having identified the brightest features with the data of other authors, to specify this scale. It goes without saying that in this portion of the spectrum the accuracy of the wavelength determination is defined by both the accuracy of this procedure and the accuracy of the data we have used, which are far from being in agreement. From our estimates the resulting accuracy of the wavelength scale in this region is no worse than 0.6-0.8 Å.

For reduction of energetic spectral orders to the energetic distribution and performing their "lacing" we have used the spectroscopic standard Feige 34. As it is pointed out in Vlasyuk (1993), this procedure excludes completely attention of an operator. The experience of "lacing" of spectral orders has led us to the inference that the second procedure is highly sensitive to both the accuracy of integration of spectra and the wavelength scale errors. It is not surprising since a simple comparison of spectral data before and after the correction for the effect of concentration of energy in the order shows that the level of the spectrum at the edges of the order may increase several times with practically unchanged value in the center.

And, finally, the last remark concerns the numeration of spectral orders adopted in this paper, which is convenient in use, but does not correspond to correct terms. The spectral orders are numbered commencing from the 1st (range 7050-7700 Å) and terminating by 13th (3100-3300 Å).

In Fig.1 is presented the whole spectrum reduced to the unified system of energetic units. Of course, most details are invisible on such a scale, however, this figure allows to estimate the high informational capacity of the spectrometer.

3. DISCUSSION

The night-sky spectrum in the region 3000-7500 Å consists chiefly of emission bands of OH and O_2 molecules, permitted and forbidden lines of O, N, Na atoms, emission lines whose origin is due to illumination lamps (Massey et al., 1990), and faint continuous radiation. Diffusion emission bands have also been registered, which are not confidently identified yet (Chamberliain, 1953).

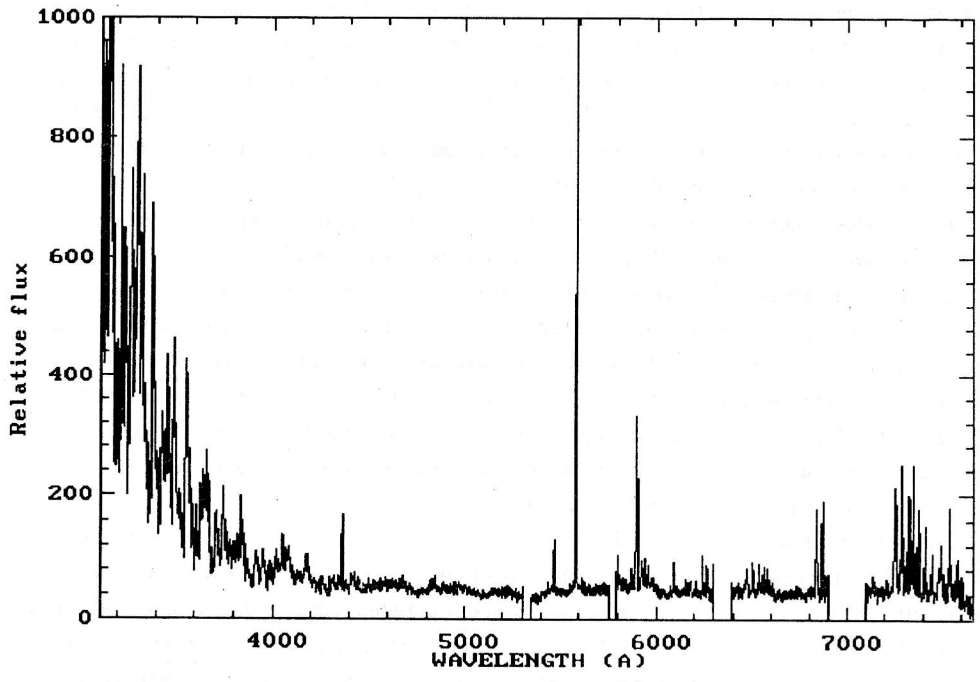


Fig.1. *The night-sky emission spectrum in the whole optical range reduced to relative energetic units.*

The night-sky air glow emission is related to faint light fluxes, however, in the observations of faint object spectra using high-sensitive light detectors a necessity arises to take into account the night-sky contribution. From the comparison of our data with the data from the papers by Ingham (1962a), Chamberliain (1955) it can be well seen that for the exposure of 1.5 hours we took the night-sky spectrum that almost completely reproduces the spectrum, the acquisition of which took about 70 hours in the run of several nights using the photographic techniques.

A schematic of the night-sky spectrum in the optical range from 3000 to 10000 Å is presented in the monographs of Worker (1990), Fishkova (1983).

a) Ultraviolet region of the spectrum (3100-4300 Å)

The night-sky radiation spectrum in the region 3000-5000 Å is formed chiefly of the emission bands of Herzberg I system of molecular oxygen (transition $A^3\Sigma_u^+-X^3\Sigma_g^-$). This system is usually designated by H, for example, H(1-7) λ3939.8 Å. The first numeral is the number of the vibrational level, the second one is the initial rotational number. The other known transitions are designated by A,B,C,D. This is described in detail by Ingham (1962a). The wavelength calculations of the series maximum or the series head were made by Herzberg, Chamberliain and Degen. The principal data can be found in Degen (1969), Herzberg (1953), Chamberliain (1955, 1958).

The emission in the bands of molecular oxygen is associated with the excitation as a result of the oxygen recombination process. The formulae are presented in the monograph of Fishkova (1983). It is noted in this paper that the results of many years of the night-sky spectrum observations show a considerable variations over the night during which the intensity of O_2 bands may change twofold.

A comparison of the night-sky spectrum taken on the 6 m telescope on the echelle spectrograph with the results of Chamberliain (1955) shows good reproducibility of all identified emission bands and emission lines (mercury). As has already been noted, the reduction to the wavelengths of orders 10,11,12,13 in the region 3100-3800 Å using of the comparison spectrum is practically impossible because of the absence of argon lines in this region. However we managed to correct the wavelength scale in these orders since the calculated wavelengths of the maximum of the series of O_2 molecule in this range are known.

The spectrum image in the region 3100-3800 Å is shown in correspondence with the spectral orders from 13 to 10 in Figs.2-5. The numbers in these figures mark the lines we have identified, and in Tables 1-4 are presented the measured wavelengths of the emission details and their identifications with the references to the papers in which this identification is corroborated.

In the spectral region from 3800 to 4300 Å (spectral orders 9 and 8) we have identified all series of oxygen molecules and several mercury lines within this region. A comparison of Figs.6,7 with the spectrum tracings reported by Ingham (1962a), where the region 3700-4500 Å is presented, shows a fit of all main details of the spectrum including unidentified.

In spite of the fact that the spectrum was taken in the moonless night the absorption lines CaII λλ3933, 3968 Å characteristic of the solar spectrum can be well seen in the spectrum, which suggests that a noticeable portion of the night-sky radiation spectrum is produced by the zodiacal light resulting from the scatter of the solar light by dust particles in the vicinity of the Earth.

b) Blue and green part of the spectrum (4300-5400 Å)

The most inexpressive part of the spectrum is from 4300 Å to 5400 Å (spectral orders 7,6 and 5 presented in Figs.8-10). The presence of numerous weak details is caused by the fact that the last weak lines of the series of O_2 molecule emit from high vibrational levels and the series of the bands of OH molecule of R,Q and P branches originate here also, which are also weak in intensity.

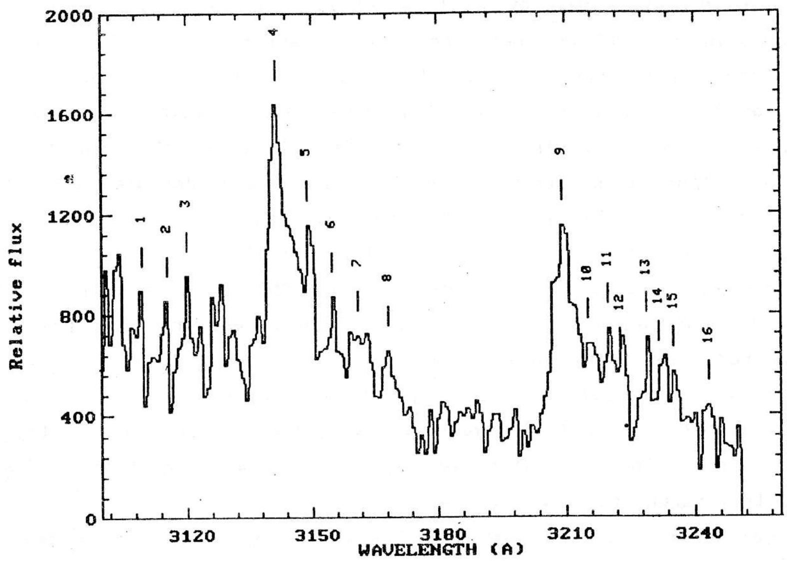


Fig.2. *The night-sky emission spectrum within λλ3100-3250 ÅÅ - 13th order. The numbers mark the spectral details listed in Table 13.*

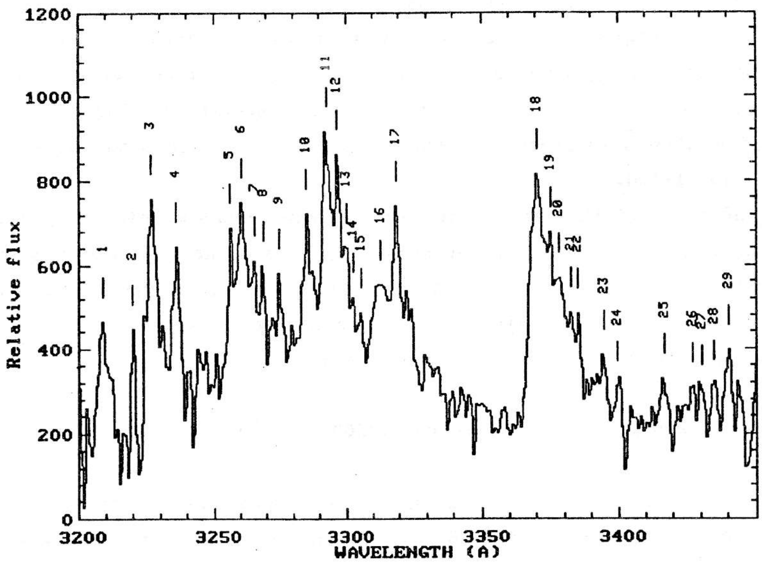


Fig.3. *The same as in Fig. 2 for λλ3200 - 3450 ÅÅ -12th order. See Table 12.*

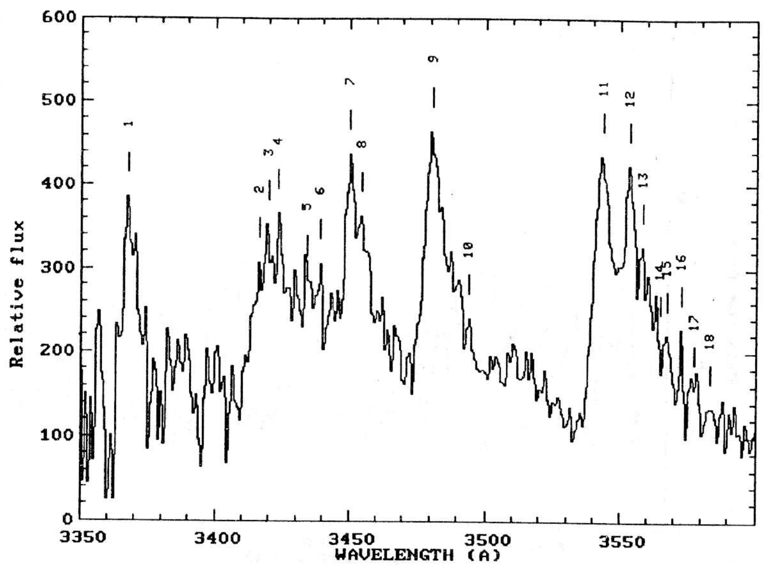


Fig.4. *The same as in Fig. 2 for λλ3350-3600 ÅÅ - 11th order. See Table 11.*

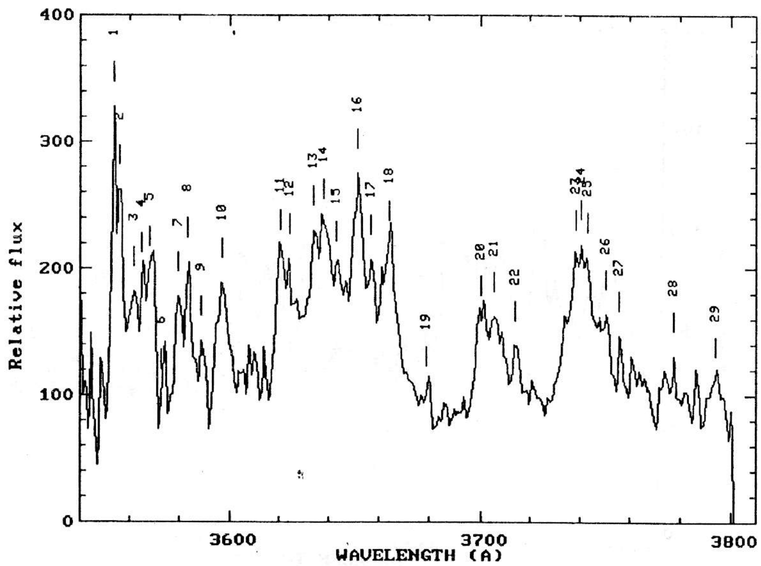


Fig.5. *The same as in Fig. 2 for λλ3550-3800 ÅÅ - 10th order. See Table 10.*

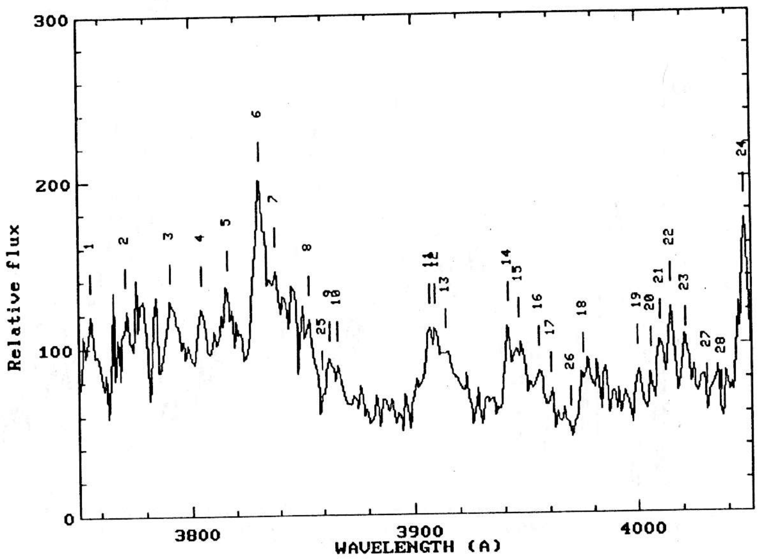


Fig.6. *The same as in Fig. 2 for λλ3750-4050 ÅÅ - 9th order. See Table 9.*

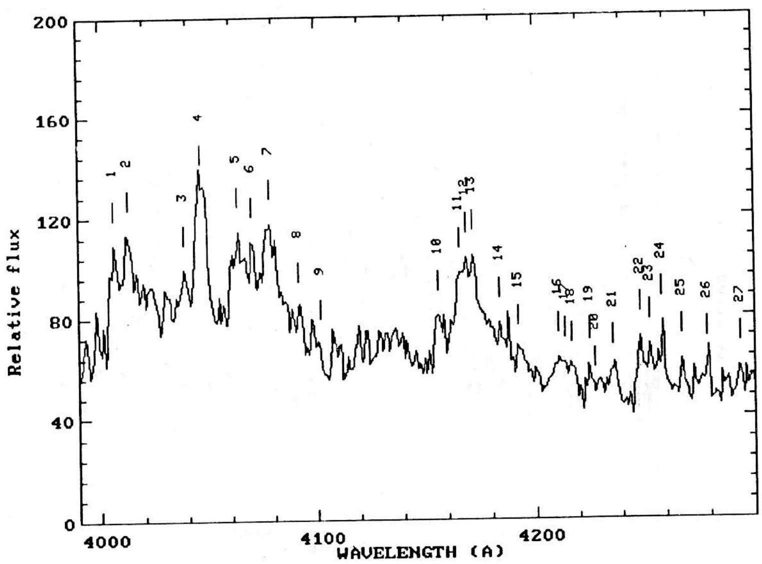


Fig.7. *The same as in Fig. 2 for λλ4000-4300 ÅÅ - 8th order. See Table 8.*

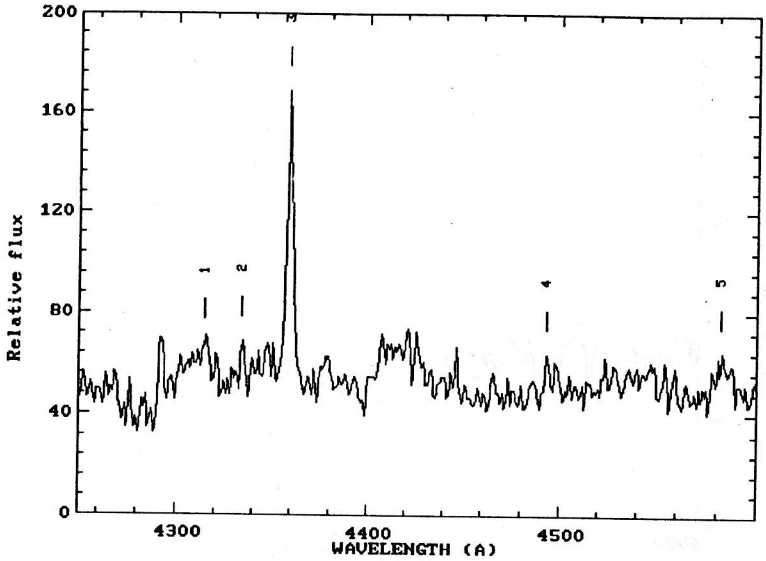


Fig.8. *The same as in Fig. 2 for λλ4250-4600 ÅÅ - 7th order. See Table 7.*

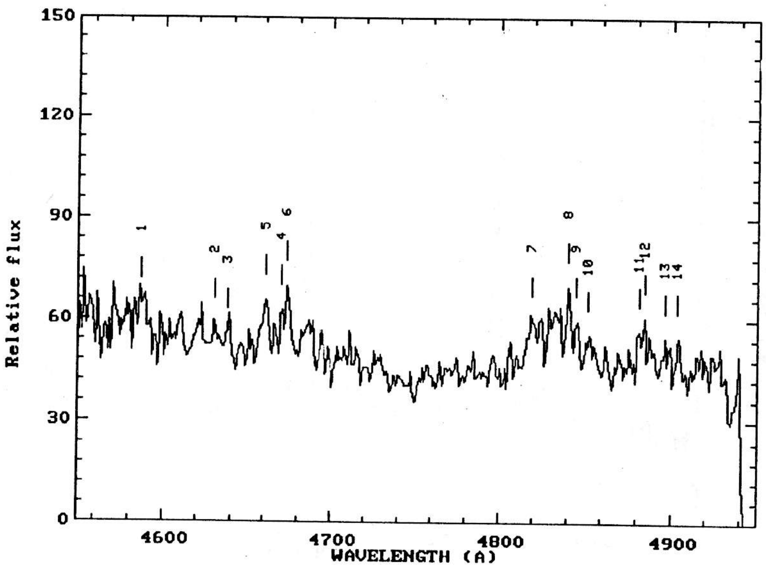


Fig.9. *The same as in Fig. 2 for λλ4550-4950 ÅÅ - 6th order. See Table 6.*

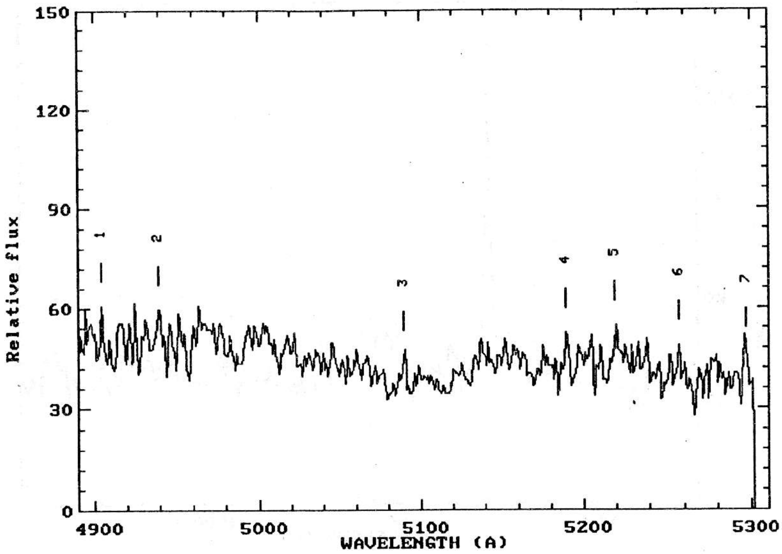


Fig.10. *The same as in Fig.2 for λλ4900-5300 ÅÅ - 5th order. See Table 5.*

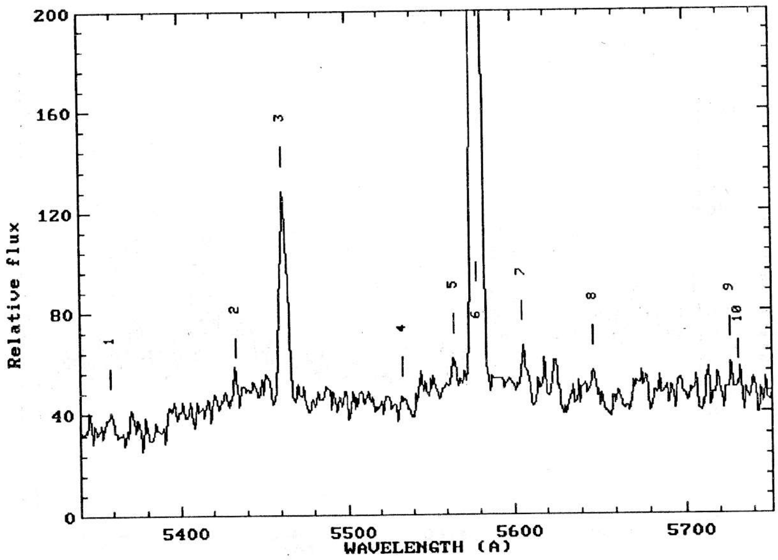


Fig.11. *The same as in Fig.2 for λλ5350-5750 ÅÅ - 4th order. See Table 4.*

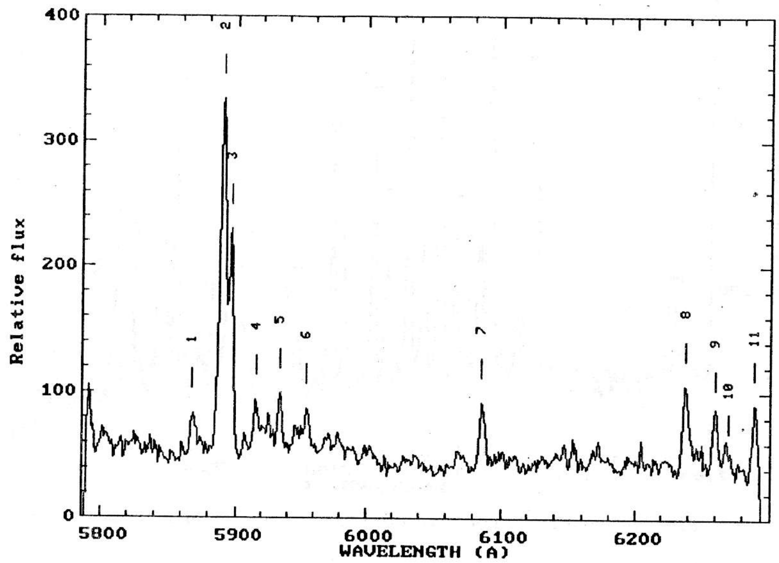


Fig.12. *The same as in Fig.2 for λλ5800-6300 ÅÅ - 3d order. See Table 3.*

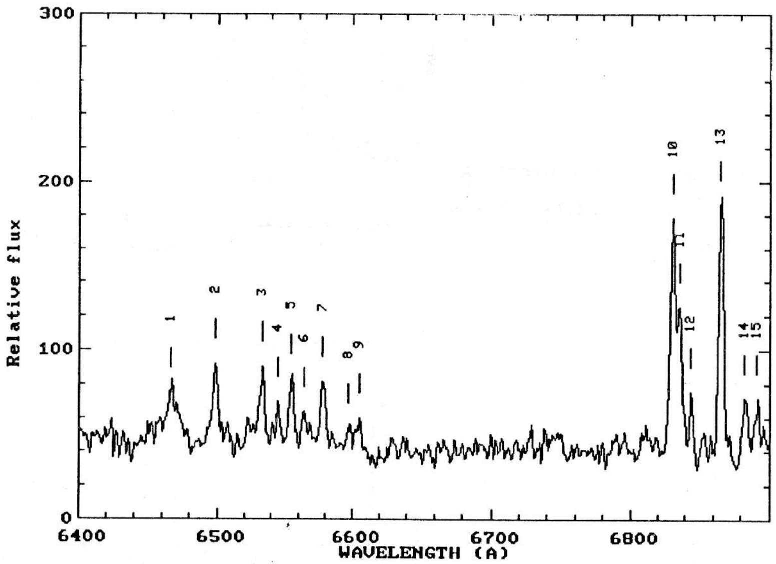


Fig.13. *The same as in Fig.2 for λλ6400-6900 ÅÅ - 2nd order. See Table 2.*

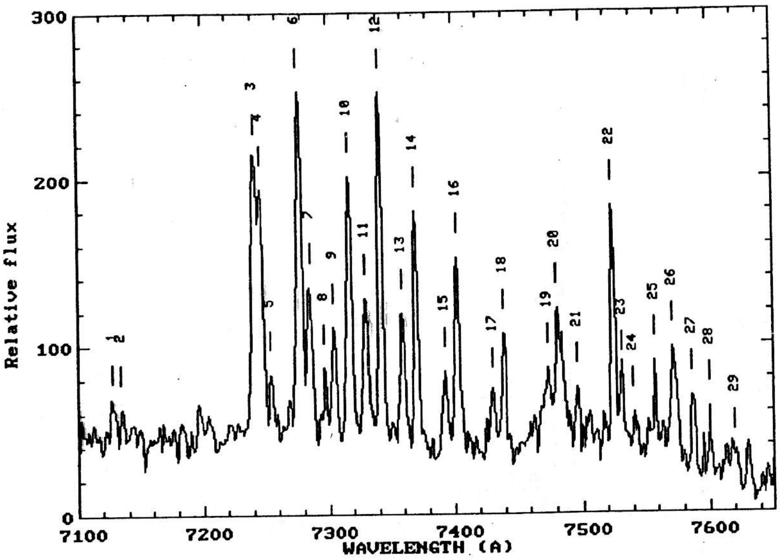


Fig.14. *The same as in Fig.2 for λλ7100-7650 ÅÅ - 1st order. See Table 1.*

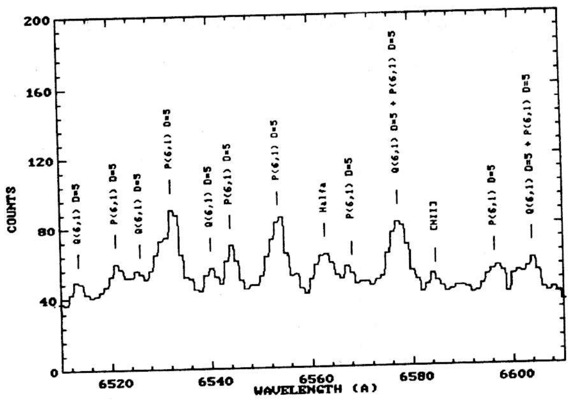


Fig.15. *Fragment of the night-sky spectrum in the vicinity of the emission line* H_α.

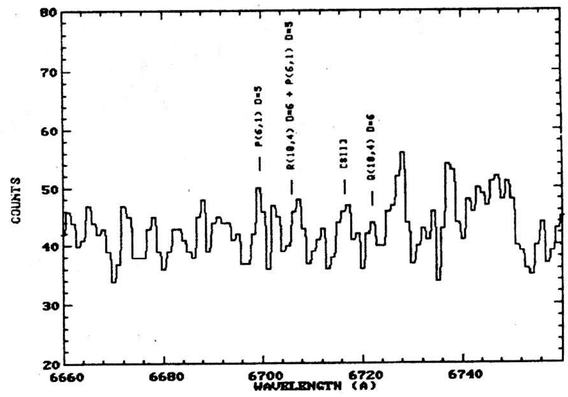


Fig.16. *The same as in Fig.15 for the line LiI.*

Fig. 17. *Fragments of the night-sky emission spectra within λλ3830 Å and 3914 Å obtained on the echelle spectrometer, October 1990 (lower), 1024-channel scanner, June 1991 (middle), echelle spectrometer, April 1991 (upper).*

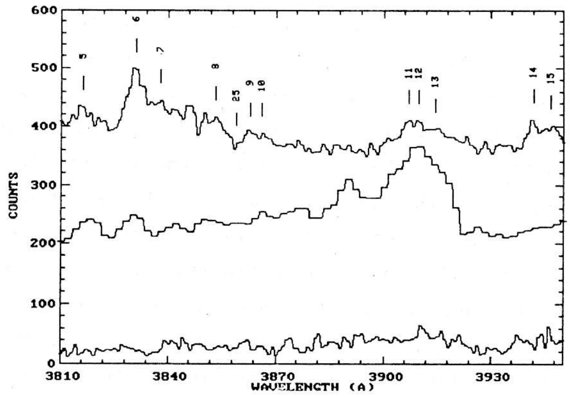
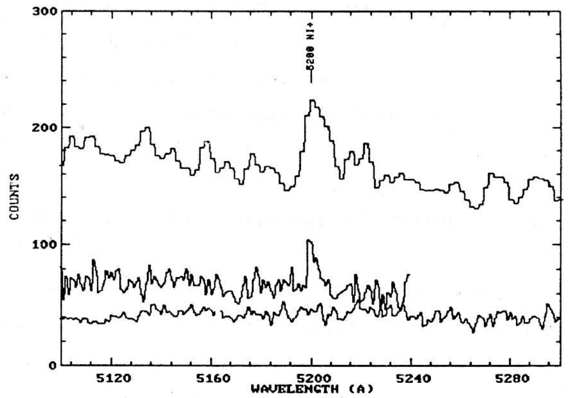


Fig. 18. *Fragments of the night-sky emission spectra in the region of the doublet NI λ5198, 5202 Å obtained on the echelle spectrometer, October 1990 and April 1991 (lower and middle), 1024-channel scanner, June 1991 (upper).*



Orders 5 and 6 are the last overlapping in wavelengths. In the region of overlapping (approximately 40 Å) the wavelengths of 6 lines coincide, one line is absent in the 6th order. Further from the 6th to the 1st there is no overlapping between the orders. Therefore some known emission lines (e.g. [OI] λ6300 Å) are absent in our Tables since they fall within the intervals between the orders.

In this region of the spectrum the line of neutral hydrogen H_β is observed, and one may suspect the presence of the known magnesium triplet MgIb, the origin of which is apparently due to the above mentioned zodiacal light.

c) Red region of the spectrum (5400-7700 Å)

And at last the region 5400-7600 Å, where orders 4,3,2 and 1 are, is represented by Figs. 11-14. Two groups of emissions are present here. These are the emission rovibrational bands of the ground state of OH molecule and the most well known to all observers emission lines of oxygen, natrium and mercury.

For this range one may apply to Blackwell (1960), where the record of the region

5500-6400 Å is presented. From a comparison with the order 3 it can be seen that in the band OH of P branch the spectra obtained on the 6 m telescope and in this paper coincide down to the weakest members of the series. In the region of H_α line the resemblance of the spectra is good too, which can be seen from the comparison of the tracings in Ingham (1962b) and the spectra in order 2. Fig. 15 shows the enlarged fragment of the spectrum near H_α with identification of all spectral details.

It seems interesting to investigate the spectrum region near λ6708 Å, where the resonance line of LiI is often identified using a low resolution data. Detailed study of this region (Fig. 16) shows the presence of several weak lines related to P(6,1), Q(10,4), R(10,4), which apparently excludes the possibility to observe the above-mentioned line, at least under the conditions of unexcited atmosphere.

From a comparison of order 1 with the paper of Chamberliain and Roesler (1955) in the region 7200-7700 Å it can be seen that the spectrum with the dispersion 70 Å/mm does not provide adequate information for complete identification of the bands OH(8.3) and OH(4.0) in the branches R,Q,P as compared to the spectra obtained on the 6 m telescope.

d) Variability of individual spectral lines

Variation of atmospheric conditions cause the appearance in the night-sky radiation spectrum of emission features which are absent in it under normal conditions. Let us pay attention to 2 such regions. In Fig. 17 is presented the spectrum region λλ3800-3900 Å registered with our echelle spectrometer in April 1991 (upper spectrum), on the 1024-channel scanner in June 1991 (middle). Lower is a fragment of the spectrum being analyzed. Fragments of these spectra in the region λ5200 Å are displayed in Fig. 18. On the spectra taken in 1991 one can see emission details with λ3830, 3914 and 5200 ÅÅ belonging to the atom NI and nitrogen molecule N_2^+, which are absent in October 1990 data (Blackwell et al., 1960).

4. CONCLUSION

The result we have obtained demonstrates high efficiency of the moderate resolution echelle spectrometer of the 6 m telescope for spectral investigation of faint objects. The compiled atlas of the night-sky radiation spectrum is of certain interest in the reduction of spectral data obtained with a good signal-to-noise ratio and moderate (of the order of 1 Å) spectral resolution.

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Table 1. Identification of lines of the night-sky radiation spectrum in the 1st order

No.	λ_{meas}	Identification	Reference	Reference
1	7126.6			
2	7133.6			
3	7240.5	R(8.3) ΔV=5 7240.6	[11]	
4	7244.6	R(8.3) ΔV=5 7244.9	[11]	
5	7252.6	R(8.3) ΔV=5 7253.0	[11]	
6	7275.6	Q(8.3) ΔV=5 7276.2	[11]	
7	7284.3	Q(8.3) ΔV=5 7284.2	[11]	
8	7295.7	Q(8.3) ΔV=5 7295.7	[11]	
9	7302.7	P(8.3) ΔV=5 7303.9	[11]	
10	7316.1	P(8.3) ΔV=5 7316.0	[11]	
11	7328.6	P(8.3) ΔV=5 7328.9	[11]	
12	7340.8	P(8.3) ΔV=5 7340.7	[11]	
13	7357.9	P(8.3) ΔV=5 7358.3	[11]	
14	7368.5	P(8.3) ΔV=5 7369.4	[11]	
15	7391.9	P(8.3) ΔV=5 7391.9	[11]	
16	7401.9	Q(8.3) ΔV=5 7402.2	[11]	
17	7429.3	P(8.3) ΔV=5 7429.4	[11]	
18	7438.2	P(8.3) ΔV=5 7437.7	[11]	
19	7472.8	R(4.0) ΔV=4 7474.0	[11]	
20	7479.5	R(4.0) ΔV=4 7480.6,		P(8.3) ΔV=5 7478.9 [11]
21	7495.0	R(4.0) ΔV=4 7494.4	[11]	
22	7523.2	Q(4.0) ΔV=4 7524.1,		P(8.3) ΔV=5 7523.6 [11]
23	7530.3	Q(4.0) ΔV=4 7531.0	[11]	
24	7539.6	Q(4.0) ΔV=4 7539.2	[11]	
25	7556.9	P(4.0) ΔV=4 7557.8	[11]	
26	7570.9	Q(4.0) ΔV=4 7569.7,		P(4.0) ΔV=4 7571.9 [11]
27	7585.7	Q(4.0) ΔV=4 7585.3,		P(4.0) ΔV=4 7586.2 [11]
28	7599.0	P(4.0) ΔV=4 7598.8	[11]	
29	7619.3	P(4.0) ΔV=4 7618.2	[11]	O_2(0-0)band 7620 [19]

Table 2. Identification of lines of the night-sky emission spectrum in the 2nd order

No.	λ_{meas}	Identification	Reference	Reference
1	6465.2	R(6.1) ΔV=5 head	[11]	
2	6497.9	Q(6.1) ΔV=5 6498.6	[11]	
3	6531.6	P(6.1) ΔV=5 6533.2	[11]	
4	6543.8	P(6.1) ΔV=5 6544.3	[11]	
5	6553.3	P(6.1) ΔV=5 6554.0	[11]	
6	6562.8	H_α 6562.82	[16], [17]	
7	6576.6	Q(6.1) ΔV=5 6576.7	[11]	
8	6596.4	P(6.1) ΔV=5 6597.1	[11]	
9	6603.8	Q(6.1) ΔV=5 6603.9		P(6.1) ΔV=5 6604.2 [11]
10	6829.4	R(7.2) ΔV=5 6829.8	[11]	
11	6834.7	R(7.2) ΔV=5 6834.4	[11]	
12	6842.2	R(7.2) ΔV=5 6842.3	[11]	
13	6864.2	Q(7.2) ΔV=5 6864.0	[11]	
14	6881.3	Q(7.2) ΔV=5 6881.6	[11]	
15	6890.5	Q(7.2) ΔV=5 6891.5		P(7.2) ΔV=5 6889.5 [11]

Table 3. Identification of lines of the night-sky emission spectrum in the 3d order

No.	λ_{meas}	Identification	Reference		Reference
1	5866.5	R(8.2) ΔV=6 5866.3	[11]		
2	5889.7	Na D1 5889.95	[16]		
3	5895.7	Na D2 5895.92	[16]		
4	5914.3	P(8.2) ΔV=6 5915.2	[11]		
5	5932.5	P(8.2) ΔV=6 5932.8	[11]		
6	5953.2	P(8.2) ΔV=6 5953.5	[11]		
7	6085.2	[OI] 5577 overlapping			
8	6236.3	R(9.3) ΔV=6 head		P(5.0) ΔV=5 6236.2	[11]
9	6258.4	Q(9.3) ΔV=6 6258.0	[11]		
10	6269.0	P(5.0) ΔV=5 6268.5	[11]		
11	6287.9	P(9.3) ΔV=6 6287.3		Q(9.3) ΔV=6 6287.0	[11]

Table 4. Identification of lines of the night-sky emission spectrum in the 4th order

No.	λ_{meas}	Identification	Reference		Reference
1	5357.8	Q(6.0) ΔV=6 5358.2	[11]		
2	5431.7	?			
3	5460.2	HgI 5460.7	[8]		
4	5532.3	R(10.3) ΔV=7 head	[11]		
5	5563.1	Q(7.1) ΔV=6 5563.6 head	[11]		
6	5577.2	[OI] 5577.35	[16]		
7	5604.6	P(7.1) ΔV=6 5605.2		P(10.3) ΔV=7 5604.6	[11]
8	5645.5	P(10.3) ΔV=7 5646.2		P(7.1) ΔV=6 5645.0	[11]
9	5725.4	?			
10	5730.3	[NII] 5730	[20]		

Table 5. Identification of lines of the night-sky emission spectrum in the 5th order

No.	λ_{meas}	Identification	Reference		Reference
1	4903.8	Q(8.3) ΔV=7 4904.8	[11]		
2	4938.5	Q(8.1) ΔV=7 4938.8		P(8.1) ΔV=7 4937.8	[11]
3	5089.4	?			
4	5188.9	R(9.2) ΔV=7 5188.5	[11]		
5	5218.5	H(0-11) O_2 5218.5	[4]	P(9.2) ΔV=7 5217.5	[11]
6	5255.5	R(6.0) ΔV=6 5255.7	[11]		
7	5295.7	Q(9.2) ΔV=7 5294.5?	[11]		

Table 6. Identification of lines of the night-sky emission spectrum in the 6th order

No.	λ_{meas}	Identification	Reference	Reference
1	4587.1	?		
2	4629.5	R(7.0) ΔV=7 4628.6	[11]	
3	4637.4	A(2-11) O_2 4636.7	[2]	
4	4669.6	NaI	[8]	
5	4660.1	P(7,0) ΔV=7 4660.1	[11] λ_{meas}=4660	[3]
6	4672.6	P(7.0) ΔV=7 4672.3	[11]	
7	4818.7	H(4-12) O_2 4816.2	[4] [3]	
8	4839.8	λ_{meas}=4840	[3]	
9	4844.9	λ_{meas}=4845	[3]	
10	4851.7	?		
11	4880.9	H(0-10) O_2 4880.4	[4]	
12	4885.4			
13	4895.8	R(8,1) ΔV=7 4894.3	[11]	
14	4903.5	Q(8,1) ΔV=7 4904.5	[11]	

Table 7. Identification of lines of the night-sky emission spectrum in the 7th order

No.	λ_{meas}	Identification	Reference	Reference
1	4314.4	$^3\Delta_3$(3-4) 4314	[3]	
2	4333.7			
3	4358.2	HgI 4358.34	[1]	
4	4492.8	λ_{meas}=4494	[3]	
5	4581.5	λ_{meas}=4580	[3]	
6	4929.1	P(8,1) ΔV=7 4931.8	[11]	

Table 8. Identification of lines of the night-sky emission spectrum in the 8th order

No.	λ_{meas}	Identification		Reference	Reference	
1	4005.9	$^3\Delta_2(6-4)$	4005	[3]		
2	4012.1	A(0-11)	4009.3 ?	[2]		
3	4037.9	NII	4039.3 ?	[5]		
4	4046.0	HgI	4046.96	[5]		
5	4062.9	H(0-7) O_2	4063.8	[4]		
6	4069.4	OII	4069.9	[13]		
7	4077.6	HgI	4077.8	[13]		
8	4091.4	$^3\Delta_2(3-3)$	4092	[3]		
9	4101.4	4101.8	H_δ	[1]		
10	4155.0	H(3-9) O_2	4154.6	[4]		
11	4165.1	H(11-12) O_2	4165.3	[4]		
12	4168.2	H(1-8) O_2	4168.9	[4], [3]		
13	4170.9	λ_{meas} = 4171		[3]		
14	4183.0	λ_{meas} = 4184		[3]		
15	4191.7	OII 4189.8		[13]	λ_{meas}=4189 not iden.	[3]
16	4209.8	λ_{meas}=4207		[3]		
17	4213.	$^3\Delta_3(6-5)$	4213	[3]		
18	4215.7	HgII 4216.7		[13]	λ_{meas}=4215	[3]
19	4224.1	A(1-9) O_2	4225.9	[2]		
20	4226.8	CaI	4226.7	[1]		
21	4235.4	NII	4236.9	[13]		
22	4247.8	C(2-3) O_2	4245.8	[1]	λ_{meas}=4246.2	[1]
23	4252.3	A(6-11) O_2	4252.4	[2]	λ_{meas}=4252.5	[1]
24	4257.9	λ_{meas}=4256.9 not ident.		[1]		
25	4266.7	H(9-12) O_2	4266.5	[4], [2]	λ_{meas}=4266.2 not id.	[1]
26	4278.4	N_2^+4278		[12]		
27	4293.1	H(6-11) O_2	4292.5	[4]	λ_{meas}=4294	[3]

Table 9. Identification of lines of the night-sky emission spectrum in the 9th order

No.	λ_{meas}	Identification	Reference		Reference
1	3755.1	3754.7 OIII, 3754.6 NIII	[5]		
2	3770.6	H(7-9) 3771.2	[4]	possib. $^3\Delta_3$(6-3) 3771	[3]
3	3790.6	$^3\Delta_2$(6-3) 3791	[3]	C(6-3) 3791.5	[1]
4	3804.2	C(0-0) O_2 3801.6	[1]	broad emis. feature	[1]
5	3816.0	λ_{meas}=3814.2	[1]		
6	3830.9	NI 3830.4 ?	[5]		
7	3837.6	H(9-10) O_2 3835.7	[4]	NII 3838.4 ?	[5]
8	3853.0	?			
9	3862.5	$^3\Delta_3$(5-3) 3860 λ_{meas}=3861	[3]		
10	3865.8	$^3\Delta_2$(3-2) 3865	[3]		
11	3906.8	HgI 3906.4	[13]		
12	3909.4	D(4-8) O_2 3909.6	[1]		
13	3914.1	N_2^+(0-0) 3914.4	[1]		
14	3941.4	H(1-7)3939.8, H(5-9)3940	[4], [3]		
15	3946.5	OI 3947.5	[13]	λ_{meas}=3947 not ident.	[3]
16	3955.1	OI 3954.5	[13]	A(4-9) 3953.1	[2]
17	3960.4	?			
18	3975.0	H(7-10) O_2 3973.5	[4]	λ_{meas}=3974	[3]
19	3999.7	NI 3999.9	[5]		
20	4005.3	$^3\Delta_2$(6-4) 4005	[3]		
21	4009.6	A(0-11) O_2 4009.2	[2]	λ_{meas}=4009 not id.	[1], [3]
22	4014.2				
23	4020.5				
24	4046.9	HgI 4046.6	[8]		
25	3858.8	Abs. line FeI 3859.9	[1]		
26	3969.3	Abs. line CaII H 3968.5	[1]		
27	4030.2	Abs. line MgI 4030.7	[1]		
28	4036.6	Abs. line TiI 4035.8	[5]		

Table 10. Identification of lines of the night-sky emission spectrum in the 10th order

No.	λ_{meas}	Identification	Reference	Reference
1	3553.6	H(5-7) O_2max. 3552.5	[18]	
2	3555.5			
3	3561.1	H(5-7) O_2 3560.7	[18]	
4	3564.1	H(5-7) O_2 3564.0	[18]	
5	3567.3	H(5-7) O_2 3567.8	[18]	
6	3572.3	H(5-7) O_2 3572.2	[18]	
7	3579.0			
8	3582.8	H(5-7) O_2 3582.7	[18]	
9	3588.0			
10	3596.2			
11	3619.5			
12	3623.1			
13	3633.	H(4-7) O_2 3634.6	[4]	
14	3637.0			
15	3642.1	H(0-5) O_2 3640.8	[4]	
16	3650.5	HgI 3650.14	[14]	
17	3656.0	HgI 3655	[14]	H(6-8)$O_2$3656.8 [4]
18	3663.3	HgI 3663	[14]	
19	3678.2			
20	3700.	C(5-2) O_2 3696.	[1]	λ_{meas}=3699.5 [1]
21	3705.0	D(6-8) O_2 3706.8	[1]	A(2-7) 3702.0 [1]
22	3713.7	D(0-5) O_2 3713.9	[1]	
23	3737.8	H(5-8) O2 3737.7	[4]	
24	3739.9	H(5-8) O_2 3738	[3]	λ_{meas}=3739 [3]
25	3742.3	OII 3741.7	[5]	
26	3750.0	A(4-8) O_2 3749.7	[2]	
27	3755.0	OIII 3754.6,NIII 3754.6	[5]	
28	3776.8	3777.6 OII ?	[5]	
29	3793.4	D(5-8) O_2 3792.8	[1]	

Table 11. Identification of lines of the night-sky emission spectrum in the 11th order

No.	λ_{meas}	Identification	Reference		Reference
1	3367.3	max. H(3-5) 3367.5	[18]		
2	3416.				
3	3419.4				
4	3422.8				
5	3433.7	HgI 3434.7	[18]		
6	3438.5				
7	3449.7	max. H(2-5) O_2 3450.1	[18]		
8	3454.7				
9	3480.3	max.H(6-7) 3479.5 head	[18]		
10	3493.5				
11	3543.2	max. H(1-5) head	[18]		
12	3553.2	max. H(5-7) 3552.5	[18]		
13	3557.8	H(5-7) O_2 3557.9	[18]		
14	3564.2	H(5-7) $_2$3564.0	[18]		
15	3566.9	H(5-7) 3567.8	[18]		
16	3572.9	H(5-7) 3572.2	[18]		
17	3576.9	H(5-7) 3577.2	[18]		
18	3583.1	H(5-7) 3582.7	[18]		

Table 12. Identification of lines of the night-sky emission spectrum in the 12th order

No.	λ_{meas}	Identification	Reference		Reference
1	3208.7	max.H(3-4) head 3209.3	[18]		
2	3219.5	H(3-4) O_2 3218.7	[18]		
3	3226.5	H(3-4) O_2 3225.5	[18]		
4	3235.8	H(3-4) 3234.0?	[18]		
5	3256.6	max. H(7-6) 3257.1	[18]		
6	3260.2	H(7-6) O_2 3262.3?	[18]		
7	3265.6	H(7-6) O_2 3265.0	[18]		
8	3268.3	H(7-6) O_2 3268.2	[18]		
9	3274.1	?			
10	3284.7	max.H(2-4) O_2 3284.3	[18]		
11	3292.4	max. H(4-5) 3292.6 head	[18]		
12	3297.0	H(4-5) O_2 3297.3	[18]		
13	3299.5	H(4-5) O_2 3299.7	[18]		
14	3302.	H(4-5) O_2 3302.6	[18]		
15	3306.0	H(4-5) O_2 3306.0	[18]		
16	3312.4	?			
17	3318.1	?			
18	3370.0	max. H(3-5)3367.5	[18]	λ_{meas} =3369.8	[18]
19	3374.7	H(3-5) O_2 3374.6	[18]		
20	3377.8	H(3-5) $_2$3377.5	[18]		
21	3381.9	H(3-5) 3380.9	[18]		
22	3384.8	H(3-5) 3384.7	[18]		
23	3394.3	H(3-5) 3393.9	[18]		
24	3399.3	H(3-5) 3399.1	[18]		
25	3416.1	?			
26	3426.4	?			
27	3429.8	?			
28	3434.4	H(7-7) O_2 3435.1	[18]	Hg3434.7	[18]
29	3439.8	?			

Table 13. Identification of lines of the night-sky emission spectrum in the 13th order

No.	λ_{meas}	Identification	Reference	Reference
1	3108.4	?		
2	3114.3	?		
3	3119.9	?		
4	3141.2	max. H(4-4) head 3141.2	[18]	
5	3148.9	H(4-4) $O_2$3150.8	[18]	
6	3154.8	H(4-4) $O_2$3157.4?	[18]	
7	3161.	H(4-4) $O_2$3161.8	[18]	
8	3168.1	?		
9	3209.0	max. H(3-4) head 3209.3	[18]	
10	3214.9	H(3-4) $O_2$3213.8	[18]	
11	3219.8	H(3-4) $O_2$3218.7	[18]	
12	3222.4	H(3-4) $O_2$3221.9	[18]	
13	3228.9	H(3-4) $O_2$3229.6	[18]	
14	3231.7	H(5-5) $O_2$3232.1	[18]	
15	3235.	H(3-4) $O_2$3234.0	[18]	
16	3243.	H(5-5) $O_2$3242.1	[18]	H(3-4) 3244.4 [18]

NOTES

[1] - Ingham, 1962a; [2] - Herzberg, 1953; [3] - Chamberliain, 1958; [4] - Degen, 1969; [5] -Striganov, 1966; [8] - Massey, 1990; [11] - Piterskaya, 1977; [12] - Eather, 1969; [13] - Zajdel, 1962; [14] - Fletcher, 1973; [16] - Walker, 1981; [17] - Ingham, 1962b; [18] - Chamberliain, 1955; [19] - Witt, 1979; [20] - Kvifte, 1959.