TWILIGHT HELIUM EMISSION AT HIGH LATITUDES

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ABSTRACT: *Regular observations of the helium emission λ 10,830 Å at the Loparskaya station (φ = 68.3°, λ = 33.1°) during the winter periods in 1960-1963 showed that the helium emission is observed only in those twilight spectra which have intensities from 200 Rayleighs and less to 3000 Rayleighs. A strong helium emission, with an intensity of more than 2000 Rayleighs, is observed, as a rule, during high magnetic and solar activity, but there is not direct correlation between them. With a decrease in the solar activity from 1960 to 1963, the intensity of λ 10,830 Å did not change noticeably. During the red aurora of type A, a very intensive helium emission is always observed; however, no correlation has been found with the lower types of aurorae.*

One of the most interesting emissions of the upper atmosphere $/53$ is that of the orthohelium line $2^3P - 2S^3λ$ 10,830 Å, which was first detected in Zvenigorod (λ = 56°) during a very intensive red aurora on February 10-11, 1958 [1]. The intensity of λ 10,830 Å HeI in this aurora was about 50 kilorayleighs [2]. At the Loparskaya station (φ = 68.3°, λ = 33°), there is always a helium emission with a very high intensity present in the red aurorae of the type A during twilight, although their intensity is much less than that during the aurora on February 10-11 [3-5]. At the present, helium emission is being observed regularly at the Zvenogorod station during regular twilights on magnetically-quiet days, but this emission has lesser intensity (~ 1000 Rayleighs) than that during red aurorae [6-9]. The observations of helium emission were conducted at twilight with the aid of the Fabry-Perot etalon [10]. The emission of λ 10,830 Å He was also recorded during the solar eclipse of February 15, 1961 [11]. With the aid of a multi-scanning spectrometer, we found one more orthohelium line λ 3889 Å caused by the transition $3^3P - 2^3S$ [12]. Its intensity was 1 $\pm$ 0.5 Rayleighs, which conforms rather well with the measured intensity of λ 10,830 Å. The intensity of the line λ 3889 Å HeI was only half that which would be expected from the measurements of the intensity of the λ 10,830 Å emission [2,6,8], and twelve times less than the estimates of McElroy [13].

In articles [2] and [6], the assumption was first set forth that the emission of the line λ 10,830 Å HeI is the result of the

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resonance scattering of solar emission by metastable orthohelium atoms in state 2^3S.

The principal mechanism for the formation of metastable orthohelium atoms is the excitation of the helium atoms by electrons with energies of about 25 eV which arise as a result of photo-ionization of the atoms and molecules by the ultraviolet solar radiation [7-9]. The role of the processes related to the lines $\lambda\lambda$ 584 and 537 Å in the solar radiation, as well as with the processes of recombination, is practically inessential [6-9]. This was confirmed in articles [13-15]. According to the latter calculations the intensity of the λ 10,830 Å emission caused by these processes is no more than 10 Rayleighs.

During the aurorae, there should be an additional mechanism for excitation of the metastable orthohelium atoms, as a result of an increase in the ionization caused by the intrusion of electron fluxes with energies of about 10 KeV. Electrons with such high energies will penetrate to an altitude of about 100 km and cause all the characteristic emissions of aurorae. However, our observations of the helium emission in the auroral zone showed that λ 10,830 Å HeI correlates weakly with the emissions which are charac-/54 teristic of lower types of aurorae. Moreover, we often found cases when a very intensive helium emission was observed without any visible forms of aurorae [5]. Therefore, it is of interest to examine the mechanism for the additional excitation of the state 2^3S of HeI because of the direct intrusion of electrons with energies of about 25 eV [16] during the aurorae.

At the present, there are still not enough complete and accurate data on the study of helium emission, particularly at various latitudes. Therefore, additional data on the character of the λ 10,830 Å emission, particularly at high latitudes, are of definite interest in examining the planetary properties of this emission.

Apparatus and Analysis Methods

Observation of the helium emission λ 10,830 Å involves definite problems. The wavelength of the most intensive line of the triplet 2^3P-2^3S λ 10,830 Å is very close to the wavelength of the line Q_1 λ 10,831.0 Å of the OH band (5.2), as a result of which these two emissions are not resolved by our high-transmission spectral apparatus. Such an apparatus is now being used for studying the emissions of the upper atmosphere (the infrared spectrograph SP-50 with an image converter has a resolving power of about 5 Å). Moreover, the sensitivity of the apparatus in the region of λ 10,830 Å is not sufficient for photographing the spectra with a brief exposure, which is necessary for an accurate determination of the relationship between the intensity of λ 10,830 Å He and the angle of solar depression. All this produces great uncertainties in calculating the intensity of λ 10,830 Å, and complicates analysis of

regularities in the behavior of λ 10,830 Å in relation to various geophysical factors.

As during previous years (1960-1961 [3-5]), the spectra in the region λ 10,830 Å were obtained on an infrared spectrograph SP-50 with an image converter tube (ICT). However, multi-stage image converters have been used recently for receivers of infrared emission. These converters provided for shortening the exposure time down to one hour and even to several minutes. Unfortunately, in February, 1963, when the observations were conducted with the aid of very sensitive image converters, the intensity of the helium emission was very low. Therefore, we could not obtain a detailed picture of the distribution of intensity with altitude, although the sensitivity of the apparatus did allow for this.

As we have already said, the helium emission is blended with the very intensive line Q_1 ($I_{Q_1} \sim$ 1000 Rayleighs) in the OH band (5.2). The intensity of the helium line is determined as the difference between the total emission in λ 10,830 Å and the intensity of the line Q_1, which was deduced by the intensity of the lines in the P-branch for the corresponding rotational temperature of the OH band (5.2). With such a method for determining the intensity of the helium emission, there arise a large number of errors. First of all, we find the regular photometric error, which in our case did not exceed 10-15% of the measured emission. Secondly, we have the error in deducing the intensity of the line Q_1, caused by the errors in determining T_{rot}(OH). This error was also small, since T_{rot} changed insignificantly during one night and from night to night ($\pm$ 20° K) [17]. Thirdly, an error in evaluating the absolute intensity of the OH band (5.2) is involved. This was a very substantial error. It comprised the error in absolute calibration of the apparatus, the disregard of transmittance of the atmosphere (which can change during the night), and the poor regulation of the sensitivity of the apparatus. The etalon tube was usually photographed once every night, at the end of photographing the spectra. /55 Since the spectrographic measurements usually lasted many hours in succession (in December, for 15-18 hours), the transmittance of the atmosphere and the sensitivity of the apparatus could change substantially, since the change in the temperature of the air effects the sensitivity of the film, while the changes in the feeding regime affected the sensitivity of the image converter, etc.

Therefore, we assumed that there would be no great error if we considered that the intensity of the OH band (5.2) was constant and equal to 10,000 Rayleighs. Our long-term observations of the hydroxyl emission in the auroral zone showed that the average variations in intensity of the OH band (5.2) were no greater than 20-30% [17]. The maximun changes in intensity of the OH band (5.2) did not exceed a factor of two. But such changes in intensity are observed very infrequently. The diurnal variations of the hydroxyl emission, according to more accurate electrophotometrical observations in the region of λ 9000-10,500 Å, also do not exceed $\sim$ 30% [18].

Figure 1 shows microphotograms of the most characsersitic spectra of the hydroxyl emission containing the helium emission of λ 10,830 Å. We can clearly see in Figure 1(a) the change in intensity of 10,830 Å in relation to the angle of solar depression ($\Delta z_\odot$). The intensity of the hydroxyl emission is roughly identical for all the evening spectra. However, the intensity of the hydroxyl emission decreased moticaably by morning ($\sim 30\%$). Roughly identical intensities of hydroxyl emission are observed frequently during the morning and evening, and from day to day. However, the intensity of the helium emission sometimes undergoes significant changes which are not related to the changes in intensity of the hydroxyl emission. We can see in Figure 1(b) that, on November 27, 1961, there was practically no helium emission, and that on the following day, during the same hours, there was observed an increase in the intensity of λ 10,830 Å, and a very intensive helium emission appeared during the morning. But such sharp changes in I_{10830} are observed infrequently.

In order to consider the effect of the spectral transmittance of the atmosphere on the value of the ratio I_{Q_1}/I_{P_1}, this value was determined for each day as the average value of several nocturnal spectra. The excess of the value for the ratio in the twilight spectra, in comparison with the nocturnal spectra, was attributed to the helium emission.

Since the helium emission blended with the line Q_1, the intensity of which is roughly 1000 Rayleighs, we cannot find a helium emission which is weaker than 100-150 Rayleighs against the background of this intensive emission (even due to regular photometrical errors). For this, we need apparatus which would completely resolve these two emissions. A helium emission of low intensity, on the order of 300-500 Rayleighs, is determined with a large error (on the order of 50%) and is sometimes not completely reliable. Figure 2 shows how the ratio $(I_{Q_1} + I_{He})/I_{P_1}$ looks for high and low helium intensities. Here, this value is plotted along the axis of the abscissa in relation to the local time. The horizontal line, which corresponds to the average minimum value for this ratio, shows the intensity of the line Q_1 in units of the intensity for P_1, while the additional emission over this level corresponds to the intensity of the helium emission, also in units of the intensity for the line P_1. The intensity of the latter is well known in absolute units.

Results of Measuring the Helium Intensity

Regular observations of the helium emission at the Loparskaya station ($\phi = 68.3°$, $\lambda = 33.1°$) were conducted during the winter periods, from January, 1960 to February, 1963. A preliminary analysis of the spectra obtained for 1960-1961 shows that the helium emission is observed only in the twilight spectra, and that, during red aurorae of type A, there is a significant intensification

Fig. 1. Microphotograms of
Certain Hydroxyl Spectra
Containing Helium Emission.
(a) Intensity of λ10,830 Å
Versus Local Time; (b) Rapid
Variations in Intensity of
λ10,830 Å from Day to Day
and During the Course of
One Day: (I) 11/27/1961,
17:15 - 18:05; (II) 11/28/
1961, 17:30 - 18:25; (III)
11/29/1961, 8:10 - 9:00.

of the HeI emission. The helium emission does not **correlate with**
the lower types of aurorae. It correlates weakly with the mag-
netic and solar activity. An intensive helium emission is observed
for a long time, sometimes for several days in a row. The observa-
tions of the following years confirmed the previously obtained re-
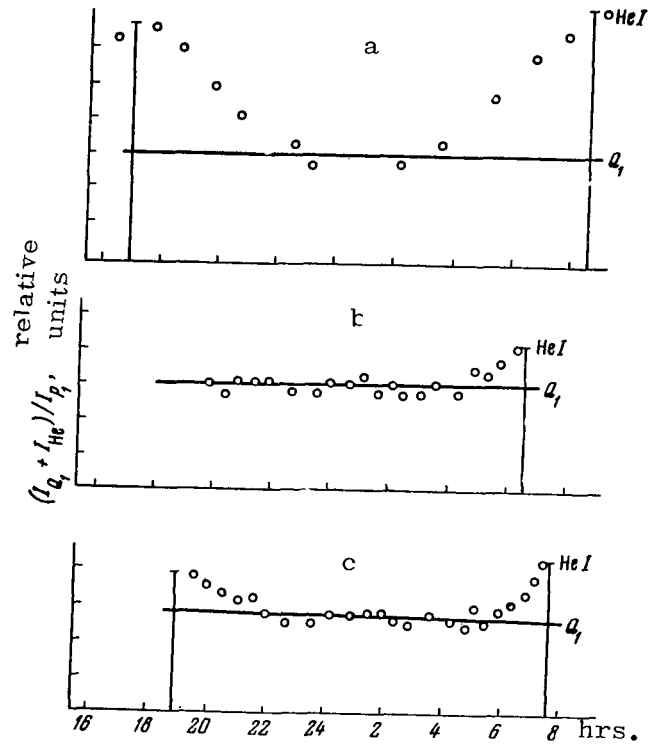sults.

Fig. 2. Some Examples of Variations in the Depend-
ence of the Ratio Between Intensity of λ 10,830 Å
and Intensity of the Line P_1 OH on Local Time.
(a) December 23-24, 1962, Aurora of the Scale-Num-
ber 2-3; (b) February 17-18, 1963, Aurora of the
Scale Number 1-2; (c) February 18-19, 1963, Airglow.

Figure 3 shows the relationship between intensity of the he-
lium emission and the angle of solar depression for certain char-
acteristic days. We can see from this Figure that a decrease in
intensity of λ 10,830 Å begins with a depression of the Sun by 10-
12°. This corresponds to a height of the geometric Earth's shadow
of about 120 km. For lesser angles of $\Delta z_\odot$, 10,830 Å does not in-
crease, and there is sometimes observered even a small decrease
in the helium intensity, which is probably related to inaccuracy
in determining the large twilight background for small angles of

the solar depression, ~ 6-8°. There is also observed an evening-morning asymmetry in the intensities of HeI, while the helium intensity during the morning is often higher than during the evening, although the opposite cases are also observed (Fig. 3). For a solar depression of 30-35°, the intensity of the helium emission decreases to zero, or more accurately, to the margin of determination by our method (100-150 Rayleighs). During some days, there is observed a rapid decrease in I_{HeI} with $\Delta z_\odot$, and during other days, there is observed a milder decrease, while there is sometimes observed /59 an uneven decrease in intensity with $\Delta z_\odot$, but the latter can be related to measurement errors because of the great fluctuations of the atmosphere's transmittance (line λ 10,830 Å is located next to a small line for absorption of water vapor, and blends with it because of the large width of the instrumental contour). The distribution of I_{HeI} with the altitude is shown more graphically in Figure 4, which was obtained from Figure 3 by the differential method. We can see in the Figure a g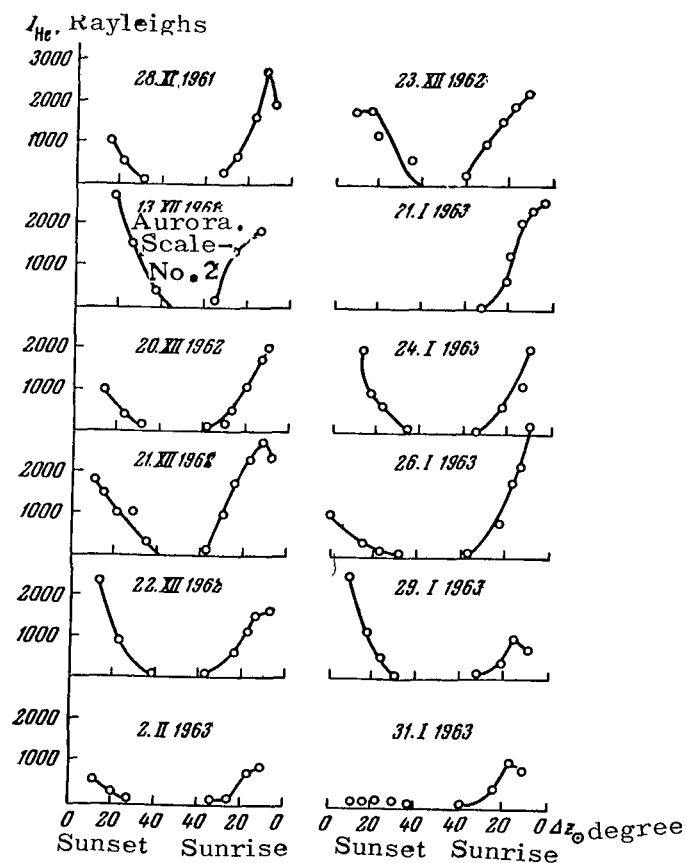reat variety in the distribution of I_{HeI} with altitude. The maximum HeI emission is not always clearly expressed, and is observed at various altitudes: from $\Delta z_\odot$ = ~ 12° to $\Delta z_\odot$ = ~ 20°, which corresponds to the altitude of the point of intersection for the boundary of the geometrical Earth's shadow and the sighting line of 120-250 km. We can see a great extension of the helium emission by altitude. The curves in Figure 4 were constructed for those days when there was observed a very intensive helium emission - on the order of 2000-3000 Rayleighs (for small values of $\Delta z_\odot$).

For low intensities of the HeI emission (on the order of 300-500 Rayleighs), the distribution of intensity by altitude could not be obtained, because of large errors in the

Fig. 3. Intensity of Helium Emission Versus Angle of Solar Depression ($\Delta z_\odot$).

measurements. At the same time, the very wide range of values for the intensity of helium emission observed at the Loparskaya station, from 200 Rayleighs and less to about 3000 Rayleighs, could be caused by various mechanisms for excitation of this emission acting at various altitudes. Therefore, determination of the alti- <u>/60</u> tude distribution of I_{HeI} for low intensities is of definite interest. However, for this, we need apparatus with high resolving power which would guarantee obtaining a non-blended helium emission.
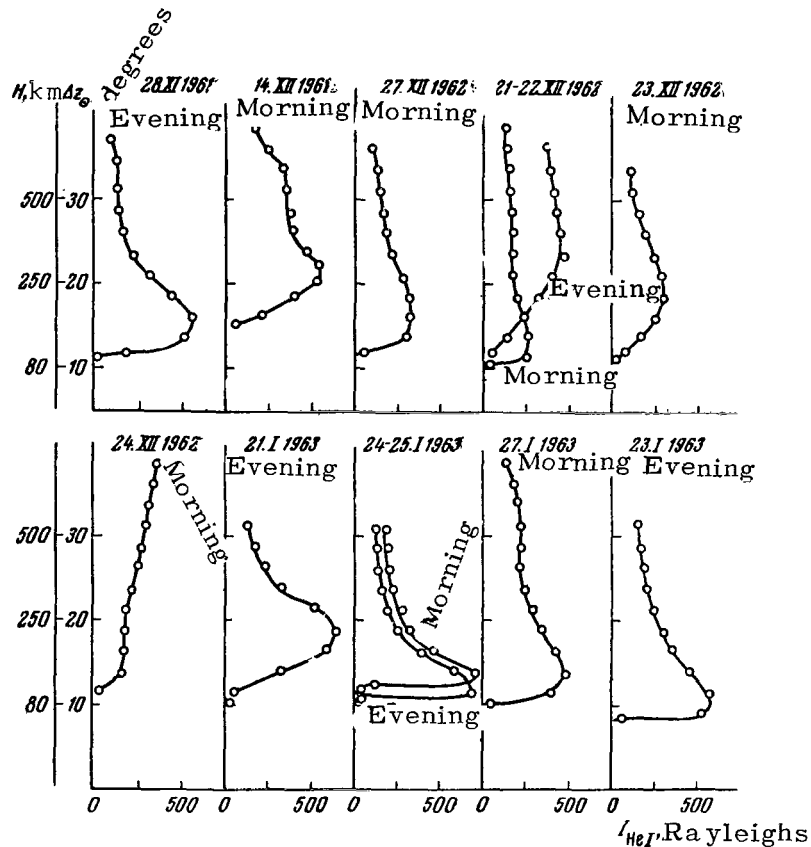

Fig. 4. Distribution of Intensity of Helium Emission by Altitude.

In a study in [5], we attempted to relate the variations in intensity of helium emission to magnetic and solar activity. In Figure 5, such comparisions were made for the entire period of observations (1960-1963). In January-March, 1969, the spectra were obtained with an exposure of several hours; therefore, we could make only an approximate evaluation of the HeI intensity, with a general consideration of the long exposure. The extimates obtained are obviously low. From November, 1960, to February, 1963, the spectra were obtained with an exposure of no more than one hour. This was completely sufficient for determining the maximum HeI intensity by early twilight spectra ($\Delta z \odot < 12°$), as can be seen in Figure 2.

An examination of Figure 5 shows that very high intensities of λ 10,830 Å HeI (more than 2000 Rayleighs), as a rule, are observed during high solar activity accompanied by a stron magnetic storm. Thus, on January 27, 1960, the intensive helium emission of more than 2000 Rayleighs was accompanied by flares on the Sun and by a large magnetic sotrm. On February 16 and 26, the intensity of helium emission reached 2500 Rayleighs. During these days, there was observed a moderate magnetic storm. On March 30, 1960, there began a great ionospheric storm which was cuased by the passing of active areas on the Sun, and which continued for several days. Particularly intense disturbances were observed on March 31-April 1, 1960, and on April 1-2, 1960. The summary K-index on these days reached values of 43 and 58, respectively. During these days there was observed a very intensive red aurora of the type A, with very intensive atomic emissions of nitrogen and oxygen. The intensity of helium emission increased rapidly from 600 Rayleighs on March 29 to 2800 Rayleighs on March 31, and 2300 Rayleighs on April 1. On November 30-December 1, 1960, a strong magnetic storm was observed during high solar activity. On this day, there was also observed a rapid increase in the intensity of λ 10,830 Å. All of December 1960 was characterized by high magnetic and solar activity. The helium intensity during this period was more than
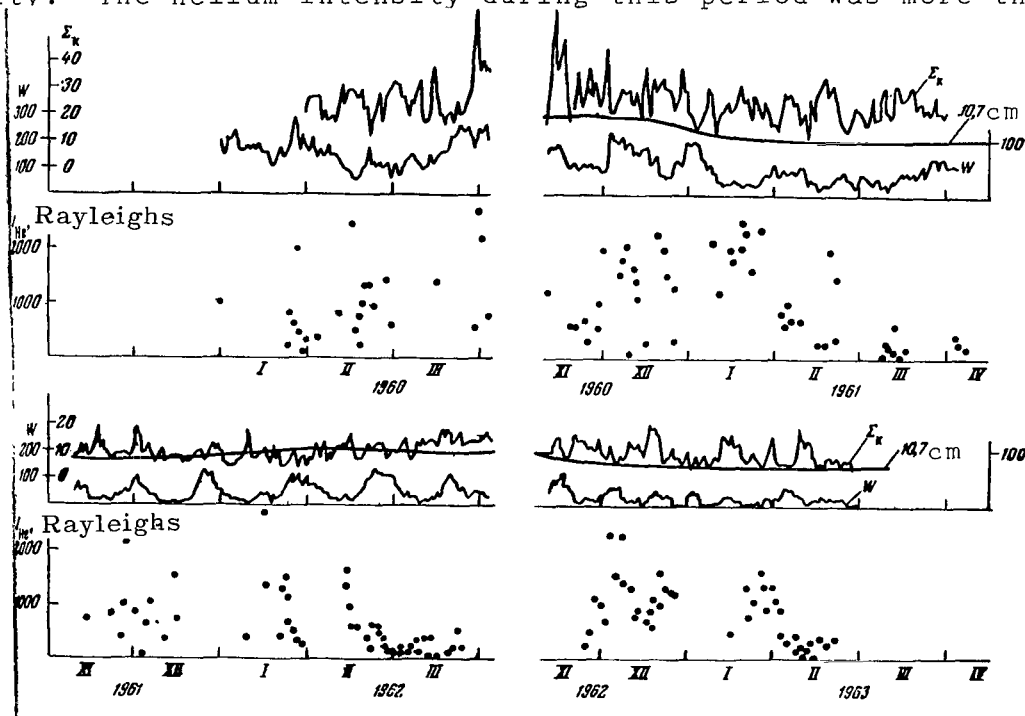

Fig. 5. Variations in Intensity of Twilight Helium Emission With Magnetic Activity (Summary K-Index, Σ_k), Solar Activity (W - Wolf Number), and Radio Emission from the Sun of 10.7 cm (averaged flux for a 27-Day Interval).

1500 Rayleighs almost all the time. The unequivocal correspond-
ance of the magnetic activity with the increase in the intensity
of λ 10,830 Å HeI was also observed on certain other days. For
example, on February 19 and 21, 1961, an increase in helium inten-
sity was accompanied by rather high magnetic activity with K_p =
6, while, on November 29, 1961, it was accompanied by high solar
activity during which we recorded several solar flares and storm
bursts.

Despite the further decrease in magnetic and solar activity
during 1961-1963, the intensity of the helium emission did not de-
crease noticeably. The intensity of λ 10,830 Å at the end of 1961
and at the beginning of 1963 (as in 1960 and at the beginning of
1961) frequently reached 2500 Rayleighs, and was often on the order
of 1000-1500 Rayleighs.

It is interesting to note that, during the three periods of
observations (November, 1960-April, 1961, November 1961-April, 1962,
and November, 1962-February, 1963), each time December was charac-
terized by a relatively high intensity (excluding the days with   /62
very high magnetic and solar activity). The variations in HeI inten-
sity in December-February were not related to the passing of the
Milky Way, since we did not photograph the twilight spectra in the
direction toward the Milky Way.

As a rule, there are no rapid fluctuations observed in the
intensity of helium emission. A high or very low intensity of helium
emission is usually observed for several days, although there some-
times occur significant changes in the intensity of helium emis-
sion, not only from day to day, but also during the course of one
day, which appears in the evening-morning asymmetry [see Figure
1(b) and Figure 3].

The helium emission is of great interest since the excited
orthohelium state is formed as a result of the effect of ultraviolet
radiation from the Sun, with $\lambda \leq$ 370 Å, on the upper atmosphere
(when there are no aurorae), or the effect of corpuscular streams
(during aurorae). This, we can determine the properties of these
agents, which cannot be found by terrestrial observations, by the
intensity of λ 10,830 Å. However, for this, we must determine the
portions of the helium emission which were caused by ultraviolet
radiation from the Sun and corpuscular excitation. At middle lati-
tudes, this picture is clearer, since an aurora, and, thus the in-
trusion of corpuscular streams, is observed only with high solar
and magnetic activity. In the auroral zone, the picture is much
more complicated, since there is not always observed an unequivo-
cal relationship between the magnetic and solar activity and the
appearance of visible forms of aurorae. As we can see from Fig-
ure 5, this relationship is found even less for the helium emis-
sion. At middle latitudes (Zvenigorod station), the intensity of
helium emission, when there are no aurorae, averages several hun-
dreds of Rayleighs. According to our data, the number of cases

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when there is helium emission with an intensity of less than 1000
Rayleighs is roughtly 45% of the total number of observations, i.e.,
at high latitudes, the atmosphere is rather frequently subjected
to the effect of corpuscular streams. But this is a rather arbi-
trary division of the sources of excitation, since the intensity
of helium emission depends on composition, density, and tempera-
ture of the upper atmosphere [9,13], as well as on the magnitude
of the exciting stream.

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