

AN EXAMINATION OF THE SPACE-TIME PROPERTIES OF HYDROXYL EMISSION

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ABSTRACT: This paper presents data on observations of the hydroxyl emission in the spectral region 8000-12,500 Å obtained with a spectrometer. The distribution of rotational temperatures is also obtained for OH bands of different vibrational levels and for their variations during the night. The spatial patches of the rotational temperature are revealed. According to their variations, the velocities of the vertical and horizontal winds are estimated for various heights of the OH emission.

Hydroxyl emission has been studied for a number of years. Numerous spectral data have been obtained with the aid of photographic recording methods. Usually the time for exposure in photographing one spectrogram was several hours. As a rule, this corresponded to observations for an entire night [1-14]. Therefore, the already well-known results are an average of the materials obtained for a long period of time. /13

More complete results are obtained with the aid of a photoelectric spectrometer. In this case, it is possible to make a rapid recording of the airglow spectra for a wide spectral range (from 8000 to 12,500 Å). It is particularly important that, with the aid of the spectrometer, there be a direct recording of the emission intensity, while spectrographic observations give photographs which require a very complex photometrical analysis related to calibration of the spectra and non-linear conversions of the blackenings on the film for the corresponding intensities. A spectrophotometrical recording of one OH band corresponding to an interval of the spectrum of about 300 Å lasts 5-6 min. This allows for examining the behavior of hydroxyl emission for brief intervals of time, and for finding the space-time variations. Such observations were conducted from November, 1963 to March, 1965, at the Zvenigrod station, on the spectro-electrophotometer DFS-14, for the infrared region of the spectrum, with a photoelectric attachment [15, 16].

The results described below were obtained with the aid of an apparatus which guaranteed linearity in the scale for the light fluxes, within a range of no less than two orders of magnitude.

We should note that, for the spectral region being studied (8000-12,500 Å), there are no sufficiently sensitive receivers of the emission. Therefore, the study with the photoelectric attach-

ment EOP + FEU was conducted almost at the margin of sensitivity. For a reliable recording of the OH emission, we had to select a certain optimal operation regime for the emission receivers and the recording apparatus. Much significance was given to the accuracy of the results obtained with the aid of the given apparatus. The error during recording was caused by various noises which, in the given case, consisted of a background noise, on the order of 1% of the entire scale, and noise in the signal which made up roughly 5% of the reading. In order to obtain data in recording the OH bands, it is necessary that the accuracy be no worse than 5% of the reading. The given value for the accuracy determines the time constant of the entire system, which was 2-3 sec. For an operating width of the slit of $\Delta\lambda = 10 \text{ \AA}$, the velocity of the spectral scanning should not exceed $70 \text{ \AA}/\text{min}$. /14

With respect to the fact that the intensities of the OH bands vary greatly and change in time, and thus the accuracy in recording them varies, we made a serious investigation for the purpose of

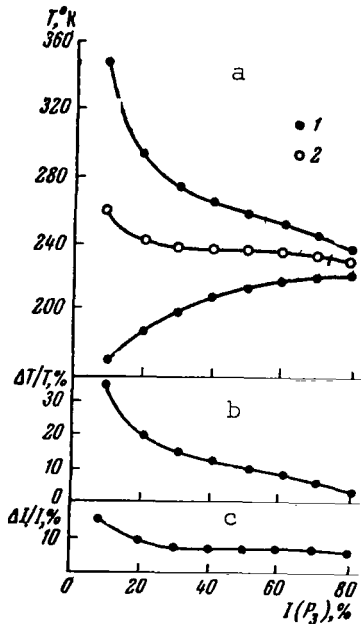


Fig. 1.

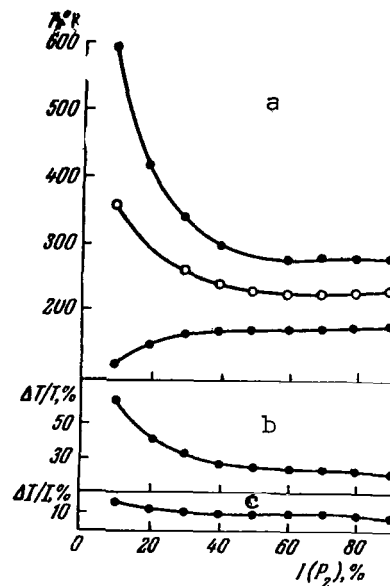


Fig. 2.

Fig. 1. Relationship Between Estimates for Errors in Rotational Temperatures of the OH Bands (4.1), (5.2), (6.3), (7.3), (8.4) and Intensity of the Bands. (a) Maximum and Minimum Scatter of T_{rot} (1) and the Most Probable Value of T_{rot} for the Given Level of Intensity (2); (b) Accuracy of T_{rot} , % (c) Accuracy of the Intensity of the Band, %.

Fig. 2. Relationship Between Estimates of Errors in Rotational Temperatures of the OH Bands (3.0) and (9.5). The Symbols are the Same as in Figure 1.

deciding the criteria for selecting data from all the material obtained. The accuracy in measuring the rotational temperature was determined with respect to the recording level of the OH band. It is well known that the T_{rot} is determined by the following formula:

$$I(J) = \text{const } v^3 i(J) \exp \left[-F(J) \frac{hc}{kT_{rot}} \right],$$

where $I(J)$ is the intensity of the line in the band, in Rayleighs; $i(J)$ is the intensity factor; $F(J)$ is the energy of the rotational level; k is the Boltzmann constant. From this, for the two lines selected, we find the following:

$$T_{rot} = - \frac{0,625 \Delta F(J)}{\Delta \log \frac{I(J)}{i(J) v^3}}$$

Thus, T_{rot} can be determined theoretically according to the difference of the logarithms for the intensities of the lines in the given band. The accuracy in determining T_{rot} depends on the accuracy in determining the intensity of the lines in the band. Therefore, we estimated that dependence. We used lines P_1 and P_2 for the reference lines. The level of the intensities on the recording was determined by line P_3 , since the ratio between the intensity of the line and the total intensity of the band depends somewhat on T_{rot} in the temperature range 150-300° K. Therefore, the variations in line intensity P_3 correspond approximately to the variations in the entire band as a whole. Figure 1 shows the data from such calculations. In the interval of wavelengths recorded, we find the bands whose temperature was determined almost alone by the two lines P_1 and P_2 , since the other lines in these bands are blended with other OH bands (bands 3.0 and 9.5). Therefore, the accuracy in determining the T_{rot} for them was calculated separately (Fig. 2). The rotational temperature for all the bands observed, as a rule, is determined by three or more lines, in addition to (3.0) and (9.5). This provides for increasing the accuracy of the measurements. On the bottom graphs in Figures 1 and 2, there is shown the relationship between the accuracy in deter- /15

AVERAGE RELATIVE ERRORS IN DETERMINING THE ROTATIONAL TEMPERATURE AND THE INTENSITY FOR OH BANDS WITH VARYING VIBRATIONAL LEVELS

v', v''	$\Delta T/T, \%$	$\Delta I/I, \%$	v', v''	$\Delta T/T, \%$	$\Delta I/I, \%$
3,0	30	5	7,3	10	5
4,1	5	5	8,4	15	5
5,2	5	5	9,5	30	5
6,3	10	5			

mining the OH intensity and the recording level in the recording. We can see from the figures that, for the bands (3.0) and (9.5), the accuracy in determining T_{rot} does not depend greatly on the level of intensity for P_2 , if its intensity exceeds 40% of the scale, and, for the remaining bands (Fig. 1), if P_3 exceeds 30%.

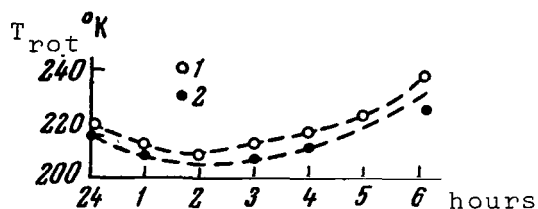


Fig. 3. Comparison of the Rotational Temperatures for the Hydroxyl Bands (6.2) and (6.3) and the Total Vibrational Level, on November 28-29, 1963. (1) - (6.2); (2) - (6.3).

spectral scanning led to a blurring of the neighboring lines in the band. We selected those recordings which had the maximum possible resolution.

Regulation of the accuracy of the rotational temperatures can also be found in the T_{rot} which is determined for the bands from one vibrational level. An example of such is shown in Figure 3, for the bands (6.2) and (6.3). The intensity of the (6.2) band on the record does not exceed 30%, and the intensity of (6.3) is 30-40%. We can see from the figure that, for the weak bands, such as the band (6.2), T_{rot} is increased, if we use the band with $P_3 \leq 30\%$ for the analysis.

In order to determine the transparency, simultaneously with spectrometry, we recorded one band with the aid of the photometer, in the spectral range 10,400 Å ($\Delta\lambda \sim 100$ Å).

The spectral region 8000-12,500 Å underwent absorption by water vapor to a great degree. The spectral regions which were most free of absorption corresponded to the bands (7.3) and (4.1). In this study, absorption by water vapor was not considered, although this could show certain changes in the results obtained. There is practically no real absorption for the hydroxyl lines in the given spectral region. However, some misrepresentations do arise because of the effect of blurring of the absorption line with the emission lines. This occurs as a consequence of the relatively large width of the instrumental contour (~ 10 Å). Nevertheless, the relative corrections for absorption do not exceed 20% for the lines in the bands (4.1) and (5.2), to which the main results of this study refer. The greatest errors can arise by not considering the

The average relative errors in determining T_{rot} and I , for various OH bands, are shown in the table. In selecting the data obtained, the first criterion was the level of intensity in the band. The second criterion was the quality of the spectral recording, i.e., the degree of allowance in individual lines in the band. With a certain change in the permeability, the quality of the spectral records decreased, since the random variations in intensity during the

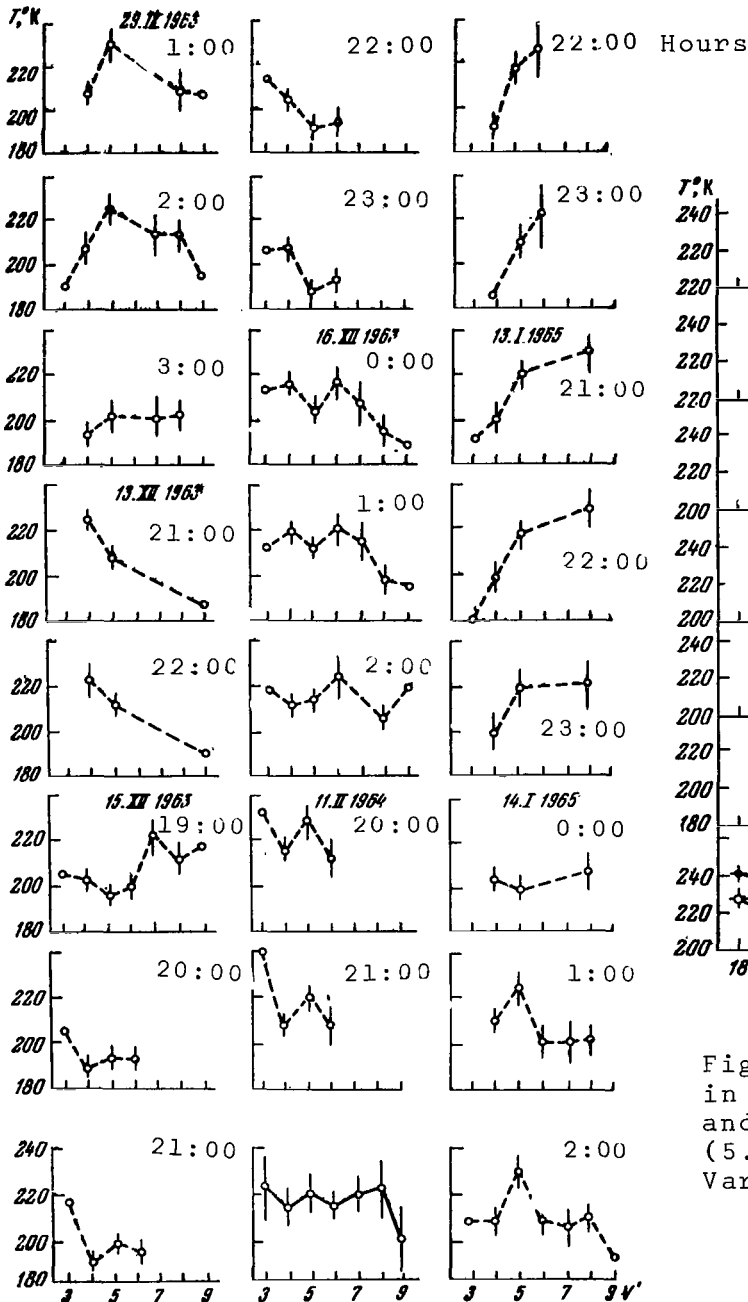


Fig. 4. Change of the Rotational Temperature According to the Vibrational Levels. The Average Distribution of T_{rot} by Vibrational Levels is Given on the Bottom Line, at the Center (The Absolute Errors for the T_{rot} are Plotted by Vertical Lines).

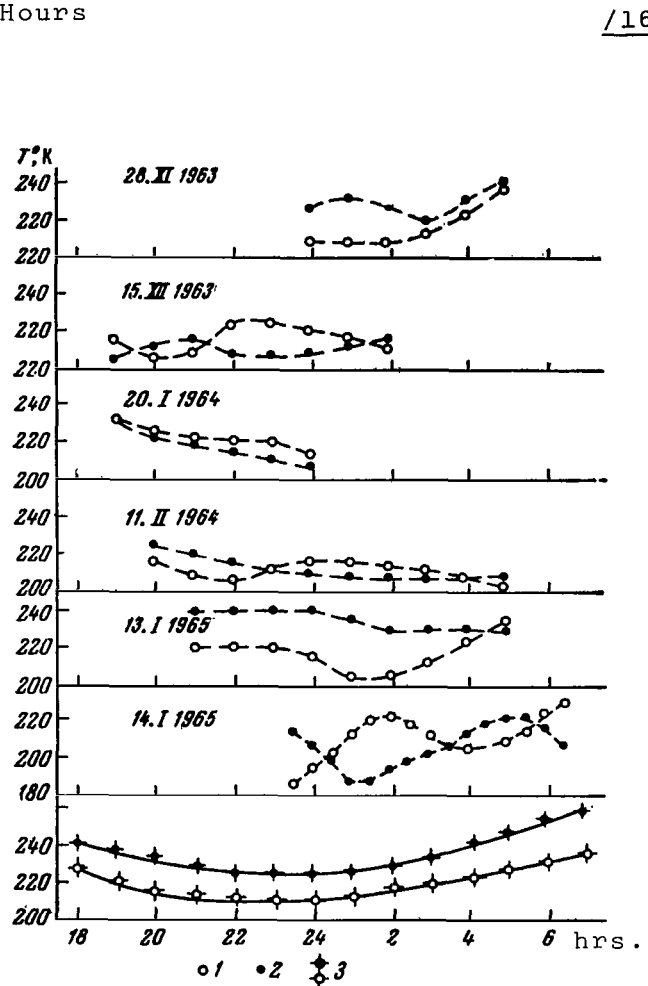


Fig. 5. Simultaneous Changes in T_{rot} for the Bands (4.1) and (5.2). (1) - (4.1); (2) - (5.2); (3) - Average Daily Variations for the Winter Months.

absorption during twilight observations, as well as on lunar nights. /18
 The data for such observations were not used in this study.

The spectral calibration was made according to the Moon and an etalon tube.

From November 1963 to March 1964, the observations were made mainly for one direction in a wide spectral range (8000-12,500 Å). The following bands were recorded: (3.0), (4.1), (5.2), (6.3), (7.3), (8.4), and (9.5). On the average, the differences in the T_{rot} for various levels was within the limits of measurement accuracy, but the T_{rot} for bands with various levels cannot differ from one another during the course of a night. Figure 4 shows examples of the distribution of T_{rot} by vibrational level during various nights.

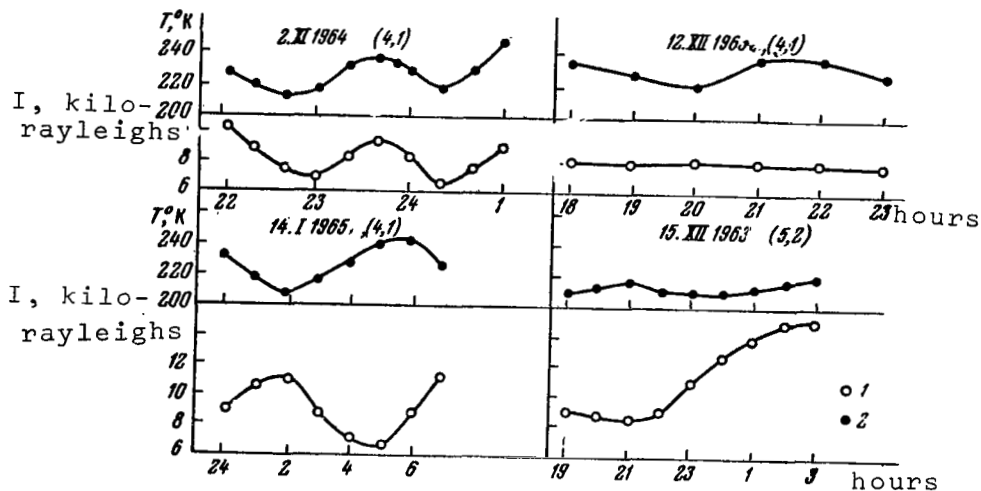


Fig. 6. Simultaneous Changes of T_{rot} and I_{OH} . (1) Rotational Temperature; (2) Intensity.

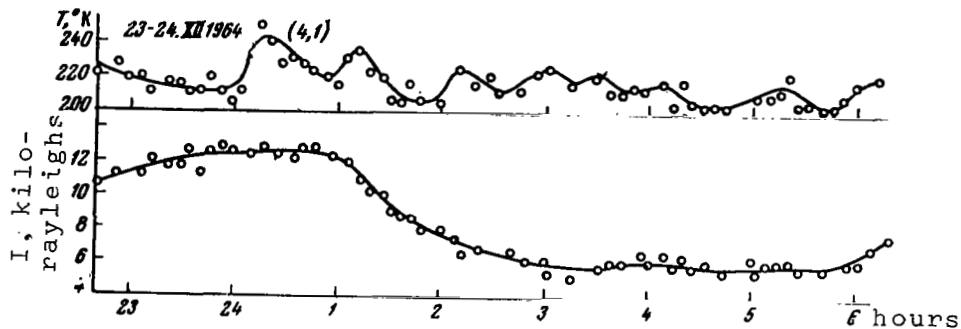


Fig. 7. Periodic Variations of the Rotational Temperature.

Because of the small degree of accuracy in determining the T_{rot} for relatively weak bands, the principal materials refer to the bands (4.1) and (5.2), which are the most intensive in this range of wavelengths. Examples of simultaneous changes in the T_{rot} of (4.1) and (5.2) are shown in Figure 5.

An examination of the simultaneous variations in intensity and rotational temperature of the OH bands had been done many times previously [11, 14]. However, in all the previous studies, only seasonal variations were considered. The correlation between intensity and rotational temperature was observed in the data of some stations, and was absent for others. The use of the spectrometer provided for obtaining information on the diurnal variations in the intensity and the T_{rot} of the hydroxyl emission. A comparison of the simultaneous values for the intensity and the rotational temperatures showed that very different cases of variations are observed. They are shown in Figure 6. However, there are most frequently found cophasal changes in the average values of the I_{OH} and the T_{rot} , against the background of which there can be fluctuations.

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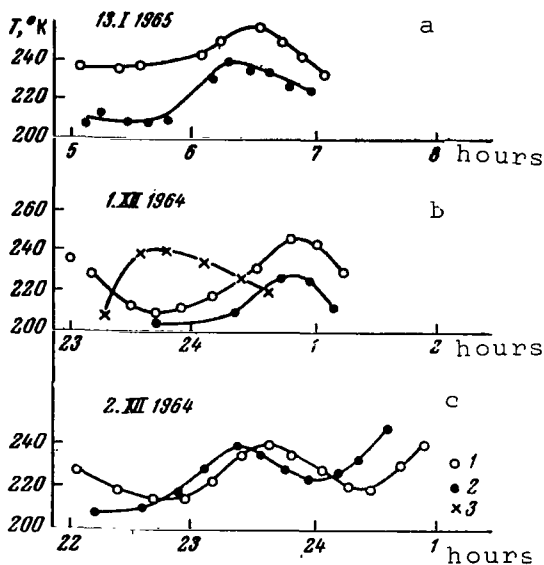


Fig. 8. Simultaneous Changes of T_{rot} at Various Regions in the Sky. (a) Direction to the East, $=15^\circ$ (1) and 40° (2); (b) Direction to the West, $=65^\circ$ (1); to the East, $=40^\circ$ (2) and 75° (3); (c) Direction to the West, $=40^\circ$ (1); to the East, $=40^\circ$ (2).

It seemed interesting to find the periodic variations in the rotational temperature. An example of such variations is shown in Figure 7. Such variations can also be seen in Figures 5 and 6.

As a result of comparing the seasonal variation in the rotational temperature of the OH bands, and the passing of the Milky Way through the field of vision of the spectrographs, we drew a conclusion on the possible effect of the interstellar OH emission. The data on the large percentage of OH molecules in the Galaxy were obtained from radio-astronomical observations [17-25]. Special observations conducted in Zvenigorod did not reveal any single effect of the position of the regions in the Milky Way on the rotational temperature of the OH bands emitted by the Earth's atmosphere. Moreover, in the observations for the area of the band, there also were changes

in I_{OH} and T_{rot} , although the stellar component does not change.

On the basis of the materials obtained, we attempted to study the simultaneous variations of the intensity and the rotational temperature in various regions of the sky. Since the spectrometer does not have the possibility of a rapid scanning of the sky, we prepared an optic system in front of the entrance slit, which provided for obtaining photometric sections along the vertical line selected. Examples of the behavior of the hydroxyl emission in various regions of the sky are shown in Figure 8. An examination of the graphs for the variations shows their similarity for different regions of the sky, but with a change in time.

It is well known that the hydroxyl emission arises at altitudes of 70-100 km [26-28], where there are horizontal winds which change sharply in direction and velocity, and also where there is a vertical movement of the air. Moreover, the OH emission is formed in the region of a temperature minimum. The variations observed in the rotational temperature of the OH bands (if this reflects the temperature of the medium) cannot be caused by a change in the temperature of the surrounding medium, but can be explained by the change in height of the emitting layers [29].

If we assume that the displacement of the curves on the graphs for the variations in rotational temperature for observations at various points in the sky is caused by the horizontal wind at an altitude of about 80 km, we can then evaluate the velocity of such a displacement. For various cases of observations, the velocity of the wind from the east to the west changes from 30 to 200 m/sec. Based on the velocities of the change in the T_{rot} , we can evaluate the absolute value for the vertical wind. According to the data of the observations, it is 1-2 m/sec. The results obtained coincide with the data on the wind velocities at these altitudes in rocket measurements, in the atomization of sodium clouds, and in the movement of meteoric trains [30-36].

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