VARIATIONS IN THE H$_\alpha$ EMISSION AND HYDROGEN DISTRIBUTION IN THE UPPER ATMOSPHERE AND THE GEOCORONA

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ABSTRACT: The variations in intensity of the hydrogen emission showed a maximum during the minimum of solar activity in 1962-1963. The distribution of hydrogen content at altitudes from 400 to 1300 km was calculated. It increased during the period of the minimum in the solar cycle. No concentration of H_α *emission around the ecliptic was detected.*

During the International Quiet Solar Year, spectral observations of the intensity of H$_\alpha$ emission 6563 Å in the airglow spectrum were conducted in Abastumani [1, 2]. /69

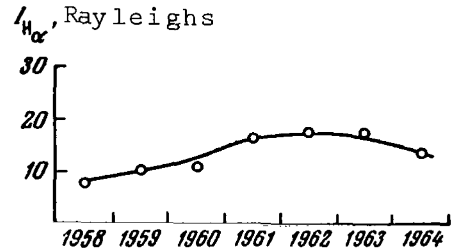

Fig. 1. Variations in the Average Annual Intensities of H$_\alpha$ Emission During the Cycle of Solar Activity.

Continuous observations from 1953 to 1964 provided for finding the annual variations in H$_\alpha$ intensity related to the cycle of solar activity (Fig. 1). With a decrease in solar activity, the H$_\alpha$ intensity increased and reached a maximum in 1962-1963 while, from 1964, it again began to decrease. Such a variation in the H$_\alpha$ intensity can be explained by the variations in the amount of hydrogen during the solar cycle. With a decrease in the solar activity, the temperature of the thermopause decreases, which then leads to an increase in the concentration of atomic hydrogen in the exosphere and the geocorona. For example, theoretical calculations [3] show that a change in temperature of the themopause from ~ 2000 to ~ 1000° K during the transition from maximum to minimum solar activity can bring about an increase in the hydrogen concentration at altitudes of 500-3000 km, almost by one order of magnitude. The data obtained on deceleration of artificial Earth satellites confirm the fact that such measurements for the temperature of the thermopause are possible. In this study, we made a hypothesis on the excitation of the H$_\alpha$ emission in the airglow as a result of scattering of the solar emission line L_β in neutral hydrogen distributed throughout the upper atmosphere and the geocorona. Then the H$_\alpha$ intensity in the given direction will depend on the height of the Earth's shadow over the observer at a given moment. Knowing the height of the shadow and the absolute intensity of H_α, $I_{H\alpha}$, we can calculate the amount of scattering neutral hydrogen atoms over the atmospheric level which corresponds to the boundary of the Earth's shadow. /70 Such calculations were made on the basis of continuous observations in Abastumani in the direction z = 67°N, and thus we obtained the values of N(H) - the number of hydrogen atoms in the pillar over the levels h , from 400 to 3000 km [4]. The calculations for N(H) were made according to the formula in [5]:

$$N(\mathrm{H}) = \frac{a I_{\mathrm{H}_\alpha} \cos\theta}{g_{32}} \cdot 10^{6} \text{ atoms/cm}^2$$

where $I_{H\alpha}$ is the intensity in Rayleighs; θ is the angle of scatter; $\cos\theta = \sqrt{1 - \frac{\sin^2 z}{(h/R_E + 1)^2}}$ (R_E is the radius of the Earth), g_{32} is the number of photons irradiated per second by one atom. The value of g_{32} is equal to $2.3 \cdot 10^{-6}$ sec^{-1}, if we consider, according to [5], that the flux πF_L in the solar line L_β is 0.5 erg/cm^2·sec, while the effective width of the line L_β is roughly equal to 0.9 Å. The coefficient a is necessary for calculating the albedo of the hydrogen in that part of the upper atmosphere which is in the shadow and which diffusely reflects the emission preliminarily scattered above the shadow. According to rocket observations, the albedo for the airglow, and the estimate obtained in [6] for the model of the hydrogen geocorona, can be taken as a = 0.67.

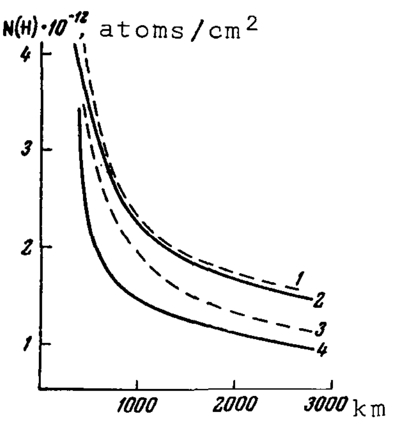

Fig. 2. The Variation in the Vertical Distribution of the Amount of Atomic Hydrogen Versus Solar Activity. Years: (1) 1963; (2) 1962; (3) 1964; (4) 1958-1959.

Figure 2 shows the distribution of N(H) for the years 1958-1959, 1962, 1963, and 1964. There is a rapid decrease in N(H) from a level of 400 to 1000 km, and then N(H) changes very gradually. The value of N(H) over 400 km, from 1958-1959 to 1962-1963, increases from $3 \cdot 10^{12}$ to $4 \cdot 10^{12}$. Moreover, the distribution of N(H) by the altitude becomes less abrupt with a decrease in the solar activity. The curve for the year 1964 goes lower than the curve for 1962, as a result of the increase in solar activity beginning in 1964. The quantity of hydrogen in the pillar over the level of 400 km [$(3-4) \cdot 10^{12}$ atoms/cm^2] was obtained here by using the value of πF_{L_β} as equal to 0.5 erg/cm^2·sec. Recent rocket observations of ultraviolet radiation from the Sun gave a value of πF_L significantly lower (~ 0.075 erg/cm^2·sec [7]). Then $g_{32} = 3.4 \cdot 10^{-7}$sec^{-1}, and the calculations of N(H) here should be roughly 7 times more.

Beginning with 1963, we had the possibility of comparing observations of the H_α emission conducted at Abastumani with observations of the H_α emission conducted at Alma-Ata [8] using the interference method. The spectrographic method used in Abastumani [1] was significantly inferior to the interference method of Shcheglov [8] in its resolving power and sensitivity. Despite this fact, the principal characteristics of the variations in intensity of the H_α emissision obtained in Abastumani conform well with Sheglov's observations. In both cases, a minimum in the H_α intensity was obtained in the antisolar direction. The ratio between the $I_{H\alpha}$ for an elongation of $\varepsilon = 60°$ and $I_{H\alpha}$ at the antisolar point was equal to ~ 3, according to the observations in Abastumani, and to ~ 4, according to Shchelgov's observations (considering the evening-morning asymmetry). According to the Abastumani observations, the H_α intensity was also greater at the end than at the beginning of a night. For example, on November 19-20, 1963, we obtained three spectra in the direction $z = 67°N$ with three-hour /71 exposures: 19:30-22:30, 22:30-1:30, and 1:30-4:30. The H_α intensity was 8, 9, and 14 Rayleighs for the first, second, and third exposures, respectively. A good agreement is also obtained for the absolute H_α intensities: during the period from December 29, 1962 to January 30, 1963, for the direction to the Celestial Pole, Shcheglov obtained $I_{H\alpha} = 2 \cdot 10^{-6}$ erg/cm^2•sec•stere, or ~ 9 Rayleighs, which, for the direction $z = 67°N$, gives ~ 13 Rayleighs. During the same period, in Abastumani (the latitude differs by 1° from the latitude of Alma-Ata), for the nights of January 27-28, 28-29, and 29-30, 1963, the values of $I_{H\alpha}$ were obtained as 10, 12, and 13 Rayleighs, respectively.

TABLE 1. CONDITIONS FOR OBSERVATIONS OF HYDROGEN EMISSION

Date	Direction of the observations	Time hrs		Zenith distances, deg		Ecliptic latitude, deg		Angles of elongation deg ω	Altitude for boundary of Earth's shadow, km.	
		t_1 beg.	t_2 end	z_1 beg.	z_2 end	β_1 beg.	β_2 end		h_1 beg.	h_2 end
28.IX 1963	Ecliptic	1	4	72	39	0	0	74	800	300
	67°			67	67	68	85	71—82	940	510
8.XI 1963	same	19	21	62	74	0	0	85	600	1340
				67	67	54	62	100—93	750	1160
8.X 1964	» »	1	4	66	38	7	7	103	2295	535
				67	67	69	83	78—87	1433	643
4.I 1965	Ecliptic	1 hr 30 min	5hrs 30 min	65	65	0	0	102—61	2866	318
	Pole of Ecliptic			68	50	90	90	90	2230	414

beg. = beginning

For 17 nights, simultaneous observations were conducted for the ecliptic and for high ecliptic latitudes, or at the pole of the ecliptic. The observations in two different directions, toward the ecliptic and at one side of it, were conducted simultaneously on two spectrographs SP-48. The resolving power for the gap-width selected (3.5 Å) is inferior to the resolving power of the narrow Fabry-Perot etalon, with the aid of which Shcheglov conducted similar observations of the H_{α} in relation to the ecliptic coordinates. In view of the fact that our observations were conducted simultaneously in two directions, and that the spectrographic method provides for a reliable recording of the continuous background, we are presenting here the data which were obtained for four nights (Table 1).

The H_{α} intensity, measured in a given direction, was corrected for atmospheric absorption and scattering in the troposphere. The intensity of the continuous background for the line of the interval 3.5 was from 3 to 10 Rayleighs Å. The relationships between the values of N(H) over the boundary of the Earth's shadow during the exposures, in both directions, were calculated according to the curves in Figure 2. In relation to the low resolving power of the spectrographic method, there could be difficulties in calculating the background, since, when there is a small quantity of scattered solar light, the superposition of the wide Fraunhofer line of H_{α} over the narrow emission line of H_{α} can distort the measured intensity of the latter. However, for directions far from the ecliptic, the continuous background, which is roughly 2-3 times weaker than the H_{α} line, related mainly to the natural illumination of the upper atmosphere in the continuous spectrum, in which there are no absorption lines. In the direction toward /72 the ecliptic, there is observed an increase in the background by no more than 1.5-2 times, because of the addition of the scattering light, in the spectrum of which there is an H_{α} line in the absorption. The calculations of this part of the background were made on the assumption that, for the selected spectral width of the gap in the spectrograph and the measured gap in the micropho-

TABLE 2. RESULTS OF OBSERVATIONS OF THE HYDROGEN EMISSION

Date	Direction of the observations	$I_{H_{\alpha}}$, Rayleighs	Background for $\Delta\lambda$=3.5Å Rayleighs	$N_1(H)/N_2(H)$	I_{ecl}/I_{2}
28.IX 1963	Ecliptic	16	10	1.3	1.3
	67°	18	4		
8.XI 1963	same	10	3	1.1	0.9
		10	3		
8.X 1964	» »	18	9	1.0	1.5
		17	7		
4.I 1965	Ecliptic	10	6	1.1	1.2
	Pole of Ecliptic	7	4		

tometer, on which the spectra were analyzed, we measured an intensity which was close to the integral. In this case, we assumed that the depth and the equivalent width of the Fraunhofer H_α line are 30% and 3.5 Å, respectively [9], and that the Doppler width of the H_α emission in the upper atmosphere and the geocorona, for 1000° K, is $\Delta\lambda = 0.2$ Å. The ratios obtained between the H_α intensity in the direction toward the ecliptic and the H_α intensity for high ecliptic latitudes or the pole of the ecliptic are shown in Table 2.

In calculating the ratios of I_{ecl}/I_z, the measured intensities were reduced to the zenith. We can see from Table 2 that the measured ratios of the H_α intensities for the two directions coincide, within the limits of error, with the ratio between the amounts of hydrogen in the column over the umbra of the Earth in these directions.

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