Doppler Profile Measurements of the Geocoronal Hydrogen Balmer Alpha Line

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Results of high-resolution measurements of the geocoronal hydrogen Balmer alpha line profile made during several nights in December 1971, May 1972, and October 1972 are presented. The measured intensities are found to be in general agreement with the theory and earlier measurements under essentially similar conditions, and the measured geocoronal hydrogen temperatures are found to be somewhat lower than the Jacchia (1971) model exospheric values.

Radiation transport of the solar Lyman beta (Lyman β) to the night side of the earth by multiple scattering on the atomic hydrogen of the earth's extended atmosphere, called the geocorona, results in fluorescence emission of the nocturnal terrestrial Balmer alpha (Hα) line [*Thomas*, 1963; *Donahue*, 1964, 1966; *Meier*, 1969; *Tinsley and Meier*, 1971]. The geocoronal Hα line has a single line profile corresponding to the fine structure transition $^3P_{3/2} \rightarrow {}^2S_{1/2}$, and since its volume emission rate peaks quite high in the exosphere [*Meier*, 1969], the temperature retrieved from its Doppler profile should indicate the true exospheric temperature. Moreover, the observed emission rate is the true emission rate, since the geocorona is optically thin to Hα radiation. Ground-based photometric observations of the Hα emission made since 1958 by many researchers in the USSR [*Krassovsky and Galperin*, 1958; *Prokudina*, 1959; *Shklovsky*, 1959; *Fishkova and Markova*, 1960; *Fishkova*, 1962; *Gaynullina and Karyagina*, 1960; *Karyagina et al.*, 1969; *Krassovsky*, 1971], Bolivia and France [*Ingham*, 1962, 1968], Norway [*Kvifte*, 1959], Australia [*Armstrong*, 1967], and the United States [*Tinsley*, 1967, 1968, 1969, 1970, 1974; *Tinsley and Meier*, 1971; *Weller et al.*, 1971] have contributed greatly to our understanding of the diurnal, seasonal, and solar cycle variations of the geocoronal Hα intensity. The present paper deals primarily with the observational results of ground-based high-resolution measurements of the geocoronal Hα line made in December 1971, May 1972, and October 1972 at the Huntsville Airglow Observatory (34.6°N, 86.6°W) of the Marshall Space Flight Center and at the Michigan Airglow Observatory (42.2°N, 83.7°W) of the University of Michigan in Ann Arbor.

INSTRUMENTATION AND RELATED INFORMATION

Observations were carried out with a Fabry-Perot interferometer having a 0.2° circular field of view and 0.25-cm spacing between the plates. The resulting free-spectral range and maximum resolution at the Hα wavelength were approximately 0.86 and 0.065 Å, respectively. The instrument width is narrow enough to resolve Hα line profiles corresponding to temperatures as low as 200°K, and the free-spectral range is large enough to avoid interorder overlap even of several-thousand-degree Doppler-broadened Hα lines. An interference filter of 5.5-Å half width (full width at half transmission) was used to isolate the Hα line from the night glow spectrum. Scanning across the line profile was accomplished by using dry nitrogen gas. Further details of the instrument are described elsewhere [*Roble*, 1969; *Atreya*, 1973].

A straightforward measurement of the geocoronal Hα line profile is hampered by the possible presence of various extraterrestrial sources, such as interplanetary, galactic, and discrete stellar, zodiacal light and gegenschein. Calculations indicate a maximum expected interplanetary Hα intensity of the order of 0.1 R [*Atreya*, 1973], which if it is detected, is expected to be Doppler-shifted from the position of the geocoronal Hα line. Diffuse and isotropic galactic Hα emissions are suspected to be quite broad and weak, and any enhanced galactic Hα emissions are confined to low galactic latitudes. Moreover, since the galactic Hα line results from a recombination process, it is expected to have a double line profile corresponding to fine structure transitions $^3D_{5/2} \rightarrow {}^2P_{3/2}$ and $^3D_{3/2}(^3P_{3/2}) \rightarrow {}^2P_{1/2}(^2S_{1/2})$, which are almost equally bright and nearly 0.14 Å removed from each other. Zodiacal light and gegenschein are like broad continuum background on which the discrete night glow features are superimposed; furthermore, zodiacal light is concentrated in low ecliptic latitudes and is visible in the evening and morning twilight. Thus the various extraterrestrial sources of Hα emission may be avoided, or their contribution minimized by selecting appropriate viewing directions and geometries of illumination, and if they are still detected, their presence may be distinguished from the geocoronal Hα line by their Doppler signatures.

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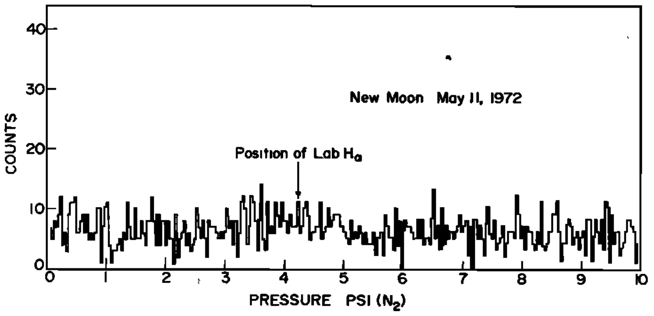

Fig. 1. Typical May 10–11, 1972, early morning Hα scan with an integration period of 5 s; lab Hα is the expected position of the geocoronal Hα line deduced from the laboratory hydrogen lamp Hα scan.

Observations, Data Reduction, and Results

Observations were made on a number of clear nights when the moon was below the horizon. No observations were carried out for solar depression angles less than 15°. In the December 1971 observations the zenith angle of observations was between 70° and 75°, and the azimuth angle relative to the sun's azimuth varied between 0° and 30°, whereas during other observing periods, two to three 'ideal points' on the celestial sphere were tracked. The ideal points, corresponding to high galactic latitudes, were selected to minimize the nongeocoronal contribution to the Hα emission. The absence of any significant amount of enhanced Hα emission in the proximity of these viewing directions was checked by several almucantar runs. Tracking of a given point in the celestial sphere ensures a constant galactic background and a constantly Doppler-shifted extraterrestrial Hα emission, if one is present.

Routine He-Ne laser calibrations of the interferometer were performed, usually prior to, during, and at the end of the night of observation to evaluate the instrument performance. A hydrogen discharge tube was used to determine the laboratory position of the Hα line. Data were recorded in the form of *X-Y* plots as well as on magnetic tapes.

A typical early morning interferometer scan is shown in Figure 1. One can barely notice the Hα interference fringe in these raw data. The average nighttime geocoronal Hα intensity was found to be less than 10 R, which for the interferometer used amounts to less than ½ count s^{-1}. Thus noise that is about 1–2 counts s^{-1} for the photomultiplier tube (ITT-FW-130) cooled to -15°C becomes an appreciable part of the signal. High-frequency noise resulting from fluctuations in the photomultiplier tube was mostly filtered out by using *Hays and Roble*'s [1971] Fourier analysis techniques. Interference fringes obtained during a night were added through their Fourier coefficients in order to improve the signal to noise ratio. The solid curve in Figure 2 shows the result of one such addition of 10 fringes. This free-spectral range was reconstructed from the first five Fourier coefficients; the principal maximum at σ_0, which lies at the laboratory position of the Hα line, corresponds to the geocoronal Hα line peak. The secondary lines in the wings of the fringe profile were analyzed to determine if they could be attributed to extraterrestrial sources. A comparison of the interference fringes reconstructed from data collected from different viewing directions on the celestial sphere on a given night was made. It was found that the positions of the principal maximum and other lines in the free-spectral range remained unchanged, thus suggesting that none of these lines were due to extraterrestrial sources, since their Doppler shift is expected to change with the viewing direction. The lines in the wings were attributed to the three hydroxyl lines of the OH(6-1) band lying approximately at +6.2, +10.7, and −9.1 Å in relation to the Hα wavelength. Owing to the lack of adequate and precise information on the intensity and positions of these hydroxyl lines their normalized theoretical profiles were generated by assuming the temperature of the

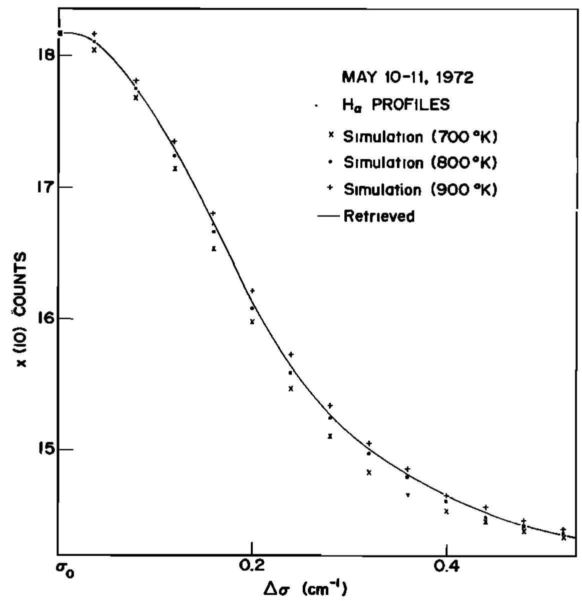

Fig. 3. Enlarged view of the overlap-free segment of the retrieved Hα fringe of Figure 2. A number of theoretically simulated Hα fringe profiles are overlaid on it to determine the mean retrieved Doppler temperature.

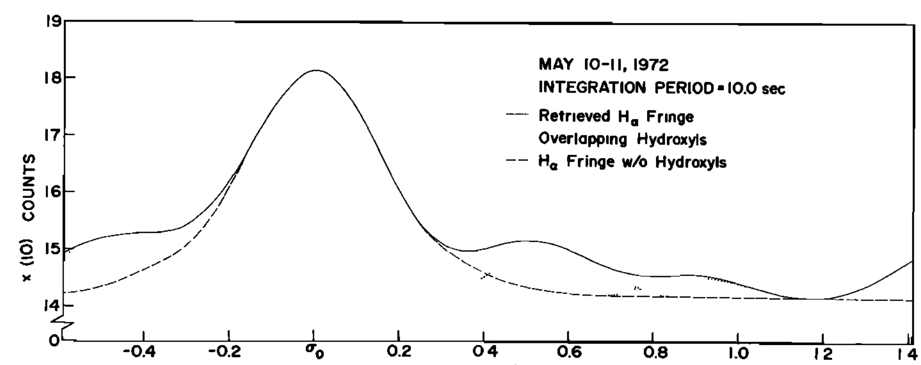

Fig. 2. Free-spectral range (2.0 cm^{-1}) of a Hα fringe retrieved from the Fourier coefficients of the May 10–11, 1972, addition of data. The solid curve is the sum of the dashed and dotted curves.

TABLE 1. Information Retrieved From the Geocoronal Hα Doppler Profile Measurements

Observation Nights	Hα Intensity, R			Doppler Temperature, °K		
	Present Measurements	*Tinsley and Meier* [1971]* Measurements	*Tinsley and Meier* [1971]* Calculations	Present Measurements (Mean Value)	Jacchia's Exospheric Value	$\overline{\Delta T}$†
Dec. 17-18, 1971	6.6	9.0	8.0	700	900	195
Dec. 18-19, 1971	9.0	9.2	8.5	800	885	180
May 10-11, 1972	8.0	7.0	7.5	850	915	210
May 11-12, 1972, plus May 13-14, 1972	9.7	6.0	6.5	800	940	170
May 15-16, 1972	9.8	7.5	8.0	850	950	200
Oct. 12-13, 1972	9.7	5.0	5.0	800	850	175

*Comparison of the present measurements with *Tinsley and Meier*'s [1971] compilations is made for the 1966 level of the solar activity with 900°K exospheric temperature and approximately the same geometry of illumination.

†$\overline{\Delta T}$ represents the standard deviation of the Doppler temperatures retrieved from the present measurements; $\overline{\Delta T}$ was computed in the manner described by *Hays and Roble* [1971].

emitting region to be 200°K. These hydroxyl lines were then removed from the Fourier-reconstructed fringe after adjusting their intensities. The clean Hα fringe obtained after removing the hydroxyl lines in the manner just outlined is shown by the broken curve in Figure 2. The purpose of this exercise is to determine the segment of the fringe profile best suited for evaluating the Doppler temperature. One notes in Figure 2 that the portion of the fringe out to about $(\sigma_0 + 0.25)$ cm^{-1} is free from superpositions. A number of theoretically simulated Hα profiles corresponding to different Doppler temperatures were overlaid on this portion of the line profile (Figure 3) to obtain an estimate of the retrieved geocoronal hydrogen temperatures. The standard deviation of the retrieved temperature was determined by using *Hays and Roble*'s [1971] error analysis techniques. An estimate of the average geocoronal Hα intensity was made from the peak amplitude of the measured signal in a manner described elsewhere [*Atreya*, 1973].

Results of measurements carried out on the nights when the best sky and moon conditions prevailed are presented in Table 1. For the purpose of comparison of these results the *Jacchia* [1971] model exospheric temperatures and *Tinsley and Meier*'s [1971] theoretical and experimental values of the geocoronal Hα intensities, both being averaged over the duration of the fringes added, are also listed in Table 1. *Tinsley and Meier*'s [1971] Hα intensities shown in Table 1 were derived from their values corresponding to the 1966 level of the solar activity with 900°K exospheric temperature and with geometries of illumination similar to those in the present measurements. Such a comparison is only approximately valid, since it is usually not possible to find observations made under 'exactly identical' conditions of the geometries of illumination, the levels of solar activity, and the exospheric temperatures. The measured geocoronal Hα intensities are found to be in general agreement with *Tinsley and Meier*'s [1971] values. The largest discrepancy in intensity is noticed for the night of October 12-13, 1972. *Tinsley* [1970] noted that sporadic variations in the geocoronal Hα intensity are possibly associated with variations in the solar Lyman β flux and in the atomic hydrogen content of the atmosphere. One notes in Table 1 that the mean measured geocoronal hydrogen temperatures are lower than the *Jacchia* [1971] model exospheric values generally by 50°-150°K. The standard deviation of the measured temperatures (last column in Table 1) is, however, rather large because of the poor signal to noise ratio even after adding a large number of interference fringes.

SUMMARY AND CONCLUSIONS

The line shape measurements of the geocoronal Hα line are found to provide a means of determining directly the geocoronal temperatures. The various hydroxyl lines in the vicinity of the Hα line are found to be the major contaminants after properly selecting the viewing directions. The absence of hydroxyl lines around Hβ wavelength makes Hβ line shape measurements appear more attractive except that the geocoronal Hβ intensity is about a factor of 10 smaller than the Hα intensity and the large signal to noise ratio is essential in order to reduce the standard deviation of the measured temperatures. The average measured nighttime geocoronal temperatures were found to be generally lower than 850°K. The mean measured temperatures are not grossly different from the *Jacchia* [1971] model exospheric values and are therefore suspected of being similar to the values that one might obtain from the thermospheric atomic oxygen red line (λ6300 Å) Doppler profile measurements. Our preliminary calculations aimed at estimating the evaporative cooling of hydrogen resulting from the escape of primarily superthermal hydrogen atoms from the exobase [*Chamberlain*, 1963] indicate that at high exospheric temperatures, which occur at midday and during geomagnetic storms, the geocoronal hydrogen temperatures T_H are expected to be considerably lower than the oxygen temperatures T_O. For T_O = 1500°K, for example, T_H is expected to be only about 1250°K. During relatively quiet conditions representative of the nights of the observations reported here, however, the calculations show no substantial difference between T_H and T_O; $T_O - T_H < 25$°K for T_O = 900°K. The average measured nighttime geocoronal Hα intensities were found to be generally less than 10 R and in general agreement with the theory and earlier measurements.

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