Planet. Space Sci., Vol. 23, pp. 1681 to 1684. Pergamon Press, 1975. Printed in Northern Ireland

PHOTOMETRIC MEASUREMENTS OF THE O_2 U.V. NIGHTGLOW

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(*Received* 29 *July* 1975)

Abstract—Measurements of the $O_2(A^3\Sigma - X^3\Sigma)$ Herzberg system in the night airglow have been made with the ESRO TD-1 satellite in the wavelength range 2400–3100 A. The slant emission rate varies from 3·5 to 15 kR, indicating an irregular structure of the atomic oxygen near the turbopause. A statistical maximum intensity is found near the tropic in the winter hemisphere. The intensity profile is consistent with excitation by three-body recombination of oxygen atoms. The observed total emission rate can be accounted for by reasonable atomic oxygen densities and an $O_2(A^3\Sigma)$ production efficiency of about 20% if quenching by N_2 occurs at the rate deduced from laboratory and other airglow measurements.

INTRODUCTION

The ESRO TD-1A satellitew as launched into a quasi-polar, synchronous orbit in March 1972. The S2/68 u.v. telescope on board was designed to scan the sky and to provide spectrophotometric data for several thousand hot stars (Boksenberg *et al.*, 1973). In accordance with its astronomical aims, the telescope was normally pointing toward the zenith at a constant altitude of about 540 km. However, during the winter period, December 1973–January 1974, the spacecraft was spinning about the stabilized axis at the rate of 1·89 deg/sec. Consequently, the optical axis of the telescope scanned a plane parallel to the terminator. Due to the precession of the orbit (1 deg/day), the satellite always crossed the twilight plane near the geographic equator. As the spacecraft moved away from the equator, the solar zenith angle of the observations varied from 90° to more than 130°. The experiment was turned on at high latitude in the dark sector and turned off when the plane of observation approached the terminator on evening passes. On morning passes, this process was reversed. The mode of operation limited the data recovery to the European sector.

Measurements of the altitude distribution of various ultraviolet emissions were made in the four channels of the experiment. We shall concentrate here on the results obtained with Channel *A*-1 (2400–3100 A) whose passsband and sensitivity were described by Boksenberg and Gerard (1973). The signal measured with Channel *A*-1 was attributed to the O_2 Herzberg system $(A^3\Sigma_u{}^+ - X^3\Sigma_g{}^-)$ since nightglow spectra indicate that it is the only bright feature observed in this spectral range (Hennes, 1966). The sampling rate of the electronics (0·148 sec), combined with the satellite spin rate, yielded one data sample each 0·28 deg, which corresponds to a layer thickness of *ca.* 13 km at an altitude of 100 km. Consequently, the field of view of the instrument (1·8 arc min) is negligible in smoothing the profile compared to the effects of the satellite spin.

Figure 1 is an example of a scan in Channel *A*-1 which clearly shows enhancement of the signal due to the Van Rhijn effect.

The excitation of the $O_2(A^3\Sigma)$ state is attributed to the three-body recombination of atomic oxygen (Bates, 1954),

$$O + O + M \xrightarrow{k} O_2{}^* + M, \qquad (1)$$

near 95 km. In this case, the volume emission rate is given by:

$$\eta = \frac{\varepsilon k[0]^2[M]}{1 + \frac{1}{A}\sum_i K_i[M_i]}, \qquad (2)$$

where A is the Einstein coefficient ($\simeq 10^{-2}$ sec^{-1}), ε is the efficiency of the three-body reaction to excite the $A^3\Sigma$ state, k is the three-body reaction rate for which recent laboratory measurements give a value of $1{\cdot}1 \times 10^{-33}$ cm^6 sec^{-1} at 200 K (Campbell and Gray, 1973), $[M]$ is the density of the third-body (essentially N_2) and K_i are the quenching coefficients.

Two indirect determinations of ε have been made (Table 1), but quenching of the $A^3\Sigma$ state was not taken into account. There is no reason to doubt that ε is satisfactorily approximated by the relative statistical weight of the A state. In this case, $\varepsilon = g(A^3\Sigma)/\Sigma_i g_i$, where g_i are the statistical weights of

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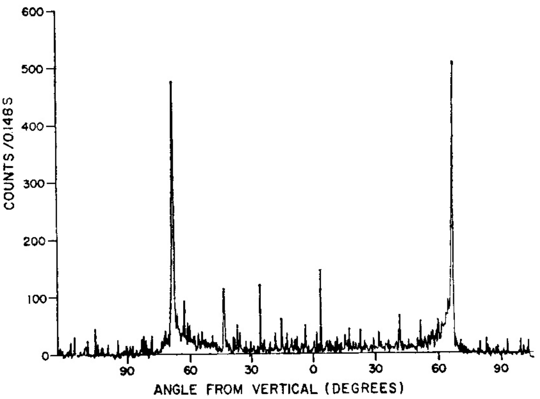

FIG. 1. EXAMPLE OF ONE SCAN IN THE 2400–3100 A CHANNEL OF THE TD-1 SATELLITE.

The limb brightening clearly seen at 67° from the vertical corresponds to an altitude of the line of sight of about 95 km.

the bounding electronic states populated in the collision of O(^{3}P) atoms:

$$g_i = (2 - \delta_{0,\Lambda_i})(2S_i + 1),$$

where δ is the Kronecker symbol; Λ and S, the molecular angular momentum and spin of the electronic state, respectively (Tatum, 1967).

TABLE 1

ε	Method	Author
0·10	Airglow observations	Sharp and Rees (1970)
0·03	Airglow observations	Reed and Chandra (1975)
0·19	Statistical weight of $A^3\Sigma$ state	

Little is known about the deactivation of $O_2(A^3\Sigma)$ in the atmosphere. Young and Black (1966) derived $K_{N_2}/A = 2 \times 10^{-13}$ cm^3 from laboratory measurements. Gadsden and Marovich (1969) deduced a value of 3×10^{-13} cm^3 for this ratio from the analysis of simultaneous measurements of the O_2 Herzberg system and [OI] λ5577 emission profiles.

LATITUDE VARIATION

About 75 scans of the dark atmosphere (SZA > 105°) were obtained during the winter period in the northern hemisphere. Adopting Degen's (1969) spectral distribution of the Herzberg system, we calculated a sensitivity of the instrument of 15·5 R/count. Auroral contamination by other emissions, such as the N_2 Vegard–Kaplan and Second Positive bands, have been excluded from this analysis by monitoring the light level in the other channels. In particular, the A-2 λ1350–1800 A channel is a very sensitive indicator of the aurorally excited N_2 Lyman–Birge–Hopfield and OI λ1356 A emission (Gerard, 1975). The observed slant emission rate, which range from 3·5 to 15 kR, is strongly variable with time and latitude. This variability reflects changes in the atomic oxygen density near 95 km and indicates an irregular and changing structure. Similar conclusions have been reached by Donahue *et al.* (1973) and Reed and Chandra (1975) from the OGO photometric measurements.

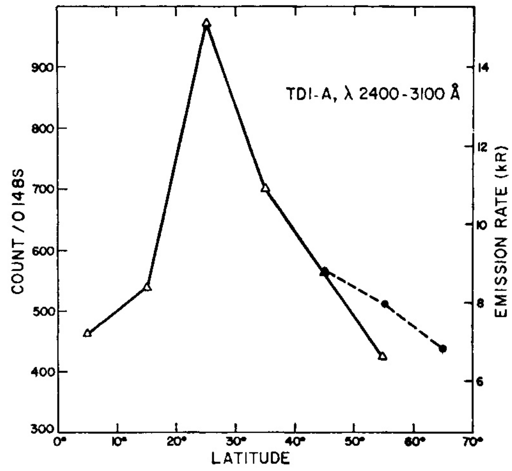

FIG. 2. LATITUDINAL DISTRIBUTION OF THE O_2 HERZBERG INTENSITY IN WINTER 1973–1974 IN THE NORTHERN HEMISPHERE.

The solid line represents the early morning data, and the dashed line indicates the evening data.

In order to uncover a statistical latitudinal variation, the emission rates have been averaged over intervals of 10° latitude after background subtraction (Figure 2). Evening data were limited to the 40–70° sector, but early morning measurements show a maximum of intensity in the tropical region and smaller intensities near the equator and at higher latitudes. This pattern is different from observations by Donahue *et al.* (1973) and Reed and Chandra (1975) who found low emission rates at low latitude, increasing poleward during winter. On the other hand, airborne measurements (Sharp and Rees, 1970) show no indication of a latitude variation of the O_2 Herzberg system. These differences might be caused by the different level of solar activity during the OGO measurements (solar maximum) and the present results (solar minimum).

ATOMIC OXYGEN DENSITY

To relate quantitatively the observed intensity to the absolute atomic oxygen density at 98 km, O and N_2 distributions were expressed analytically:

$$[O] = [O]_M \exp\frac{1}{2}\left[1 - \frac{z - z_M}{SH} - \exp\frac{-(z - z_M)}{SH}\right] \quad (3)$$

$$[N_2] = [N_2]_M \exp - \left(\frac{z - z_M}{H}\right),$$

where z_M is the altitude of the atomic oxygen density maximum, H the scale height of molecular nitrogen, and S a scale factor. $[O]_M$ and $[N_2]_M$ are the O and N_2 densities respectively at the altitude z_M. Reed and Chandra (1975) have shown that Equation (3) gives an atomic oxygen distribution close to CIRA (1968, 1972), Jacchia (1971), and mass-spectrometer profiles. In the following, we assumed the peak density of atomic oxygen, $[O]_M$, was at 98 km, in agreement with recent airglow (Donahue and Guenther, 1975) and mass-spectrometer (Trinks, 1974) measurements. Equation (2) was integrated numerically along the line of sight for values of K_{N_2}/A ranging from 0 to 1×10^{-12} cm^3. Due to the low spatial resolution of the instrument and to the minor effect of quenching on the shape of the calculated slant intensity, no information can be deduced on quenching of $O_2(A^3\Sigma)$ from these measurements. Figure 3 illustrates the comparison between three observed scans and the numerical integration of equation (2) using equation (3) with $S = 0{\cdot}8$. Since absorption by O_3 was not considered, a good agreement is not expected below about 60 km.

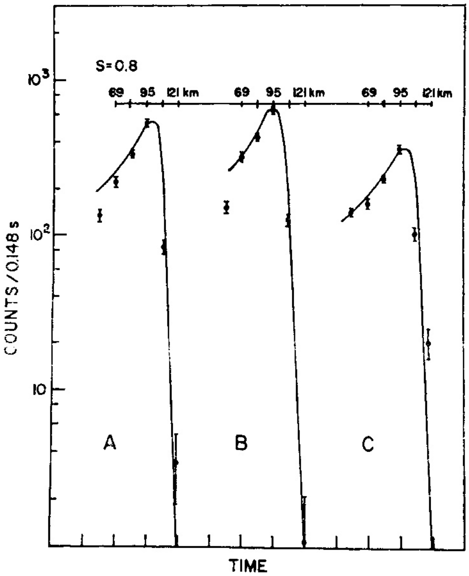

Fig. 3. Intensity of the O_2 airglow intensity measured on three different scans.

A : day 350, 30·5°N; B: day 350, 18°N; C: day 351 32°N. The solid line represents the calculated intensity using Equations (2) and (3) with $S = 0{\cdot}8$.

The relationship between $[O]_M$ and the maximum emission rate, $4\pi\mathcal{I}$ is given by:

$$[O]_M^2 = \frac{4\pi\mathcal{I} \times 10^9}{I\varepsilon k[N_2]_M},$$

where I is the horizontal integral of equation (2) for unit ε, k, $[O]_M$ and $[N_2]_M$. Taking $[N_2]_M = 1{\cdot}2 \times 10^{13}$ cm^{-3} (CIRA, 1972) and a measured average emission rate of 9kR, the maximum atomic oxygen density is found to be 3×10^{11} cm^{-3} for $\varepsilon = 0{\cdot}19$ and $K_{N_2}/A = 3 \times 10^{-13}$ cm^3. If ε is substantially smaller, the quenching coefficient must be smaller than adopted here to maintain reasonable $[O]_M$ values. Clearly, an unambiguous laboratory measurement of ε is needed before a definite conclusion can be reached.

In summary, the $O_2(A^3\Sigma \rightarrow X^3\Sigma)$ emission originating near 95 km in the atmosphere is very patchy and irregular. Measurements made in the northern hemisphere in winter 1973–1974 reveal a maximum average intensity near the tropics. The observed emission rate is accounted for quantitatively by the three-body recombination of atomic oxygen using current estimates of production and quenching rates of the $A^3\Sigma$ state. When more accurate determination of these rates are available, such measurements will provide a good sensing of the atomic oxygen density near the turbopause.

Acknowledgements—I wish to thank C. Chisholm, K. Simmons and A. Tilkin for their help in the data processing and the S2/68 team for making the data available. The telemetry operations were planned and coordinated by the European Space Operation Center (ESOC). My stay at the Laboratory for Atmospheric and Space Physics has been partially sponsored under a NATO postdoctoral fellowship.

REFERENCES

Bates, D. R. (1954). The physics of the upper atmosphere. *The Earth as a Planet* (Ed. G. P. Kuiper), pp. 576–643. University of Chicago Press, CH.

Boksenberg, A. and Gérard, J.-C. (1973). Ultraviolet observations of equatorial dayglow above the F_2 peak. *J. geophys. Res.* **78**, 4641–4650.

Boksenberg, A., Evans, R. G., Fowler, R. G., Gardner, I. S. K., Houziaux, L., Humphries, C. M., Jamar, C., Macau, D., Malaise, D., Monfils, A., Nandy, K., Thompson, G. I., Wilson, R. and Wroe, H. (1973). The ultraviolet sky survey telescope in the TD-1A satellite. *Mon. Not. R. astr. Soc.* **163,** 291–322.

Campbell, I. M. and Gray, C. N. (1973). Rate constants for $O(^3P)$ recombination and association with $N(^4S)$. *Chem. Phys. Lett.* **18,** 607.

Degen, V. (1969). Vibrational population of $O_2(A^3\Sigma_u^+)$ and synthetic spectra of Herzberg bands in the night airglow. *J. geophys. Res.* **74,** 5145–5154.

Donahue, T. M., Guenther, B. and Thomas, R. J. (1973). Distribution of atomic oxygen in the upper atmosphere deduced from OGO-6 airglow observations. *J. geophys. Res.* **78,** 6662–6689.

Donahue, T. M. and Guenther, B. (1975). Comment on "Atomic oxygen densities in the lower thermosphere as derived from in situ 5577 A night airglow and mass spectrometer measurements" by O. Offermann and A. Drescher. *J. geophys. Res.* **80,** 219–220.

Gadsden, M. and Marovich, E. (1969). 5577 A nightglow and atmospheric movements. *J. atmos. terr. Phys.* **31,** 817–825.

Gerard, J. C. (1975). Auroral ultraviolet emissions. *Atmospheres of Earth and the Planets* (Ed. B. M. McCormac), pp. 309–317. Reidel, Dordrecht, Holland.

Hennes, J. P. (1966). Measurement of the ultraviolet nightglow spectrum. *J. geophys. Res.* **71,** 763–770.

Reed, E. I. and Chandra, S. (1975). The global characteristics of atmospheric emissions in the lower thermosphere and their aeronomic implications. *J. geophys. Res.* **80,** 3053–3062.

Sharp, W. E. and Rees, M. H. (1970). Latitudinal distribution of night airglow. *J. geophys. Res.* **75,** 4894–4896.

Tatum, J. B. (1967). The interpretation of intensities in diatomic molecular spectra. *Astrophys. J. Suppl.* **16,** No. 124, 21–56.

Trinks, H. (1974). Early results of neutral atmosphere composition measurements between 90 and 230 km by the ALADDIN 74 cryogenic mass spectrometer. Paper presented at the 2nd annual meeting of the European Geophysical Society, Trieste.

Young, R. A. and Black, G. (1966). Excited-state formation and destruction in mixtures of atomic oxygen and nitrogen. *J. chem. Phys.* **44,** 3741–3751.