SATELLITE OBSERVATIONS OF THE NITRIC OXIDE NIGHTGLOW

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Abstract. The NO δ-bands have been observed photometrically by the ultraviolet telescope onboard the TD-1 ESRO satellite. The maximum intensity for the system is about 220 R, in good agreement with a previous rocket measurement. Assuming that the excitation is due to the N + O → NO(C$^2\Pi$, v=0) preassociation, we used the observed profile to derive the atomic nitrogen density distribution. We found a peak of about 9 x 107 cm-3 at about 180 km. A comparison is made with theoretical predictions, and some implications of such a high N(^{4}S) density are discussed.

The NO δ-bands have been observed in the nightglow spectrum by balloon-borne (Cohen-Sabbin and Vuillemin, 1973) and rocket-borne ultraviolet spectrometers (Feldman and Takacs, 1974). The first set of observations clearly revealed the presence of the (0,1), (0,2), and (0,3) NO δ-bands, but no absolute intensity or vertical distribution has been deduced. The rocket spectra showed features from the NO δ- and γ-systems, but the geometry of the observations was complicated by resonance scattering of the γ-bands above a shadow altitude of 215 km. The excitation of the NO(C$^2\Pi$) state was attributed to the chemiluminescent preassociation of N and O in the reaction:

$$N + O \rightarrow NO(C^2\Pi,\ v=0) \qquad (1)$$

Photometric measurements of the altitude distribution of the ultraviolet nightglow emission were obtained by the UV telescope onboard the ESRO TD-1A satellite in December 1973 and January 1974. During this period in a hibernation mode, the satellite spun about its sun-stabilized axis at a rate of 1.89 degrees/sec. Consequently, the optical axis of the telescope scanned a plane parallel to the terminator. The experiment was turned on at high latitude in the dark sector and turned off when the plane of observation approached the terminator. One of the channels, labelled A$_3$, recorded a weak signal when the line of sight scanned close to the horizon. This emission is attributed to the NO δ-bands. Fig. 1 displays three such scans recorded on 16 and 17 December 1973 at a spacecraft altitude of 540 km and at various latitudes. The altitude of the line of sight is indicated at the top of the figure. The solar zenith angle varies from 110°6 to 97°7. The dotted lines show the level of the background noise. In the

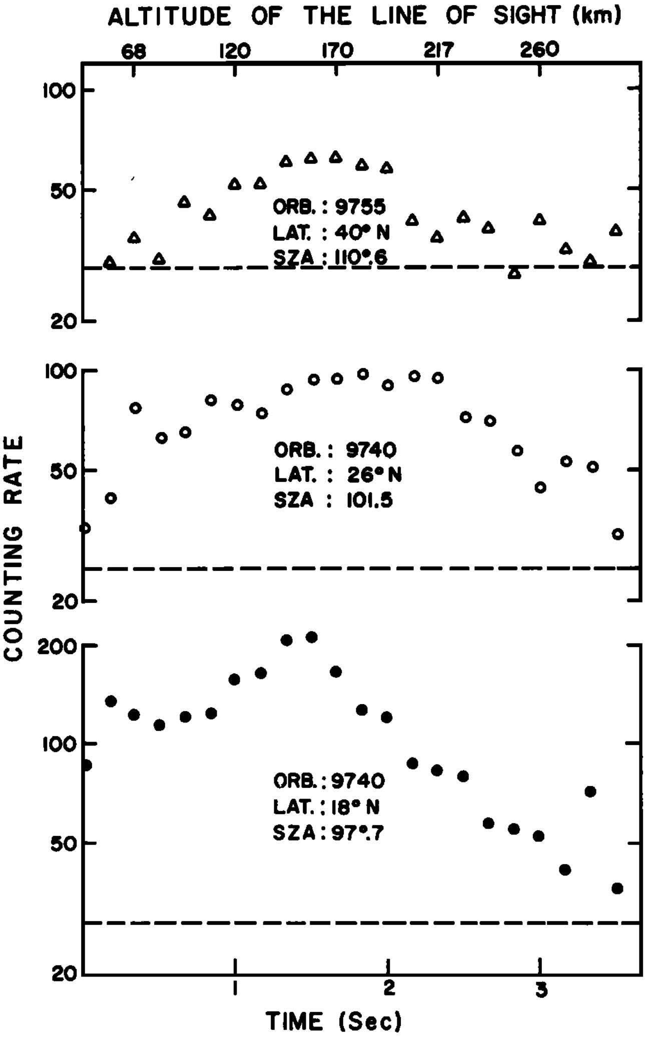

Fig. 1. Example of three horizon scans by the TD-1 UV telescope at various solar zenith angles (SZA). The dots indicate the number of counts/0.16 sec measured as a function of time.

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following, we shall concentrate on the first example for which the solar depression is large enough to prevent any contribution from the NO γ-resonance scattering in the passband (Fig. 2).

The spectral response of the A3 channel on a diffuse source (Boksenberg and Gerard, 1973) is a roughly rectangular function between 1750 and 2150 A. The sampling rate of the photon counting is 6 $\sec^{-1}$. The counting rate can be converted into absolute emission rate of the δ-system provided the spectral distribution of the intensity is known. Table 1 gives the branching ratios as calculated using a $q_{v'v''}\nu^3$ dependence with Franck-Condon factors from Ory (1964). They are compared with those deduced from high resolution recombination spectra obtained in the laboratory by Kley (1973) and with the airglow spectrum of Feldman and Takacs. The agreement among the three sets of intensities is satisfactory, and an instrument sensitivity of 6.1 R/count in the channel is deduced for the whole δ-system. A maximum intensity of about 220 R is thus observed near 165 km and the corresponding emission rate of the (0,1) band is on the order of 50 R. This value compares favorably with the 83 R measured by Feldman and Takacs for this band. The v' = 0 progression of the γ-bands is excited in the laboratory recombination spectrum. The v' = 3 progression is very weak (Kley, 1973), and, consequently there is negligible contribution from this system in channel A_3. The weak emission rate factor of the δ-bands (Barth, 1966), combined with the low abundance of NO above the shadow height, gives a negligible contribution of resonance scattering to the observed signal.

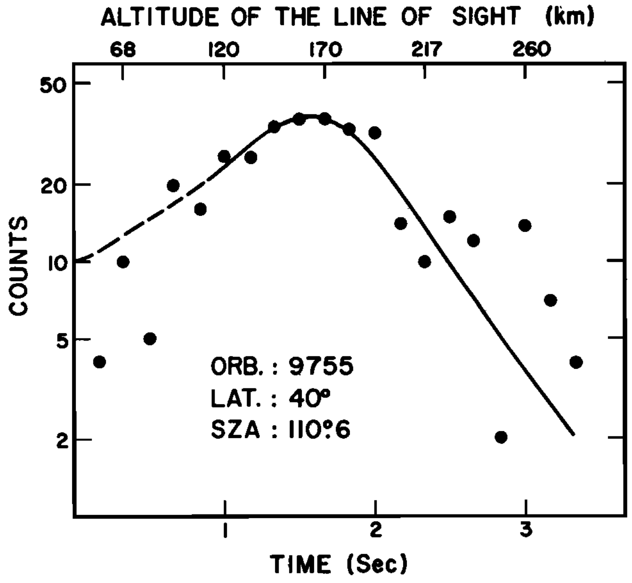

Fig. 2. Example of a horizon scan with background subtracted. The solid line is a fit to the data.

The apparent emission rate $4\pi\phi$ observed for an altitude z_o of the line of sight is related to the volume emission rate, η, by the relationship:

$$4\pi\phi_{z_o} = 2\int_{z_o}^{\infty} \eta(s)ds \qquad (2)$$

where s is the variable along the line of sight. Integral (2) must be inverted to determine the altitude distribution of η. For this purpose, a four-parameter analytical function of the form

$$F_z(H_1, H_2, z_M, A) = \frac{A}{\exp[(z-z_M)/H_1] + \exp[-(z-z_M)/H_2]}$$

was assumed to represent adequately η(z). The parameters were determined so that integral (2), with F_z as the integrand, fit the observed profile. This fit is illustrated in Fig. 2; a good agreement is not expected at low altitudes where the atmosphere is optically thick in that spectral range.

If we assume that reaction (1) is responsible for the production of the $NO(C^2\Pi)$ state, the atomic nitrogen density profile is given by:

$$[N] = \frac{F_z}{k_\delta [O]}, \qquad (3)$$

where k_δ is the total rate coefficient of reaction (1), for which recent laboratory measurements (Mandelman et al., 1973) give a value of 1.5×10^{-17} cm^3 sec^{-1}. A weak

TABLE 1.
Intensity distribution of the NO δ-bands

Transition	λ (A)	Branching Ratios		
		$q_{v'v''}\nu^3$	Lab	Airglow
0-0	1912	0.19	0.16	0.17
0-1	1983	0.29	0.22	0.25
0-2	2058	0.24	0.22	0.18
0-3	2138	0.15	0.17	
0-4[a]	2223	0.08	0.12	
0-5[a]	2314	0.035	0.06	
0-6[a]	2407	0.015	0.03	
0-7[a]			0.015	
0-8[a]			0.005	

[a] outside the channel passband.

temperature dependence of k_δ (25% from 300 °K to 600 °K) has been neglected here. The result of this calculation is illustrated in Fig. 3 where the atomic oxygen density is taken from CIRA (1972) for an exospheric temperature of 800 °K, calculated for the day of observation. The curve gives a maximum density of about 9×10^7 cm^{-3} near 180 km. The gradient below 150 km is very steep and is determined by chemical reactions.

The intensity of the signal observed is in agreement with previous spectral observations. Its altitude distribution provides a method to determine the atomic nitrogen profile in the nighttime atmosphere provided reaction (1) only contributes to the excitation of the NO δ-bands. Other similar data to be analyzed will provide information on the latitude dependence of the N density. The case illustrated in Fig. 3 corresponds to one of the brightest scans and the deduced N density must probably be considered as an upper limit.

In the range of altitude considered here, $N(^4S)$ atoms are produced by various reactions and mainly destroyed by the process:

$$N(^4S) + NO \rightarrow N_2 + O, \qquad (4)$$

whose rate coefficient is $1.5 \times 10^{-12} \sqrt{T}$ (Phillips and Schiff, 1962; Nicolet, 1965). Reaction (4) is also the dominant destruction mechanism for nitric oxide below 250 km. Consequently, the abundance of $N(^4S)$ depends on the NO density and vice-versa.

The experimental profile of Fig. 3 can be compared with recent models for the $N(^4S)$ and NO distributions. Strobel's (1971) model at 18.30 L.T. predicts a maximum density [N] ∿ 5×10^6 cm^{-3} at an altitude of 240 km with an NO density of 4×10^6 cm^{-3}. A comparison of the NO, $N(^2D)$ and the densities of major neutrals and ions locally measured by the Atmosphere Explorer C satellite was recently made by Rusch et al. (1975). They predict high quantities of $N(^4S)$ ($\approx 1 \times 10^8$ cm^{-3} at 180 km), coupled with low NO abundance ($\approx 10^6$ cm^{-3}), in very good agreement with these measurements.

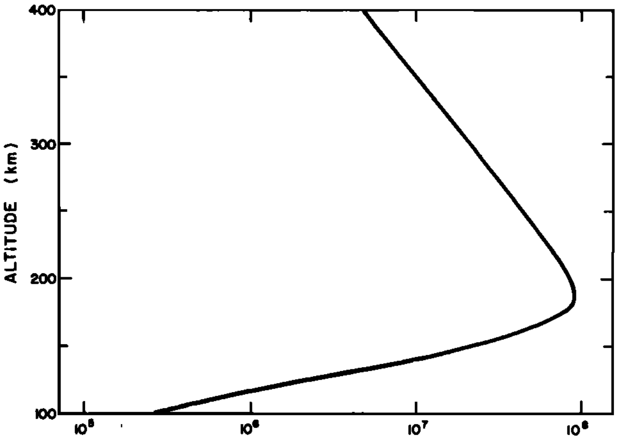

Fig. 3. Atomic nitrogen density profile deduced from the NO δ-bands intensity by inverting the solid curve of Fig. 2.

High atomic nitrogen densities are expected to have the following consequences:

1. A large density of $N(^4S)$ at early night gives very short NO lifetimes against reaction (4). Consequently, below 280 km the nitric oxide densitites can be expected to drop drastically very soon after sunset.
2. Coupling our calculation for [N] at 160 km with NO measurements by Rusch et al., [NO] ≈ 5×10^6 cm^{-3}, we found a production rate $\approx 1 \times 10^4$ sec^{-1} for NO, which is somewhat more than the upper limit predicted by models. However, the uncertainties of N and NO densities rule out an accurate comparison until simultaneous measurements of NO, $N(^4S)$ and $N(^2D)$ can be made.
3. Any analysis of the λ1200 A dayglow profile must take radiation trapping into account for such high $N(^4S)$ densities.
4. The density of N^+ ions has been extensively measured and can be used to determine whether the amount of atomic nitrogen deduced here is consistent with the N^+ density. The analysis of the N^+ distribution may also provide information on the N density.

More detailed discussion of the implication of high [N] values can be done when the variability of the amount and vertical distribution of atomic nitrogen is known. A direct simultaneous measurement of [N] and other constituents would also be most useful to clarify the N-NO reaction scheme. Work along these lines is in progress.

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