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CALCULATED [OI] 6300 Å NIGHTGLOW DOPPLER TEMPERATURES FOR SOLAR CYCLE MINIMUM

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Abstract—The effective doppler temperatures of the nightglow [OI]6300 Å line are calculated using the data of Evans (1967) for electron density and ion temperature variations throughout the night during solar cycle minimum. These temperatures are shown to follow the exospheric temperature closely but at a value of 25–50°K lower in most cases.

The neutral temperature of the upper atmosphere can be determined in principle from measurements of the doppler broadened half-widths of the forbidden atomic oxygen line shapes in the nightglow. Most measurements have been made on the 5577 Å line giving kinetic temperatures near the 100 km region where most of the night-time 5577 Å radiation originates. Only a very few measurements of the weaker 6300 Å line and associated kinetic temperatures have been carried out and these are generally high, indicating an origin in the *F*-region (Wark, 1960; Jarrett, Hoey and Paffrath, 1964; Jarrett and Hoey, 1966; Hernandez, 1967). These observations are in general agreement with the predicted neutral temperature values, although no detailed study of the expected doppler temperature variations has been carried out to date. In this paper we will use the sunspot minimum ionospheric data of Evans (1967) for electron density and ion temperature to predict the expected doppler temperatures of the nightglow red line.

The theory of the *F*-region nightglow emissions of atomic oxygen has been discussed by numerous investigators and has recently been reviewed by Peterson, van Zandt, and Norton (1966). The reactions governing the normal 6300 Å nightglow emission are:

$$O_2^+ + e \rightarrow O + O \quad (\alpha_1) \tag{1}$$

$$NO^+ + e \rightarrow N + O \quad (\alpha_2) \tag{2}$$

$$O^+ + O_2 \rightarrow O_2^+ + O \quad (\gamma_1) \tag{3}$$

$$O^+ + N_2 \rightarrow NO^+ + N \quad (\gamma_2). \tag{4}$$

On using these reactions in conjunction with the equations of continuity and charge neutrality the emission rate for the 6300 Å line becomes, (Peterson *et al.*, 1966)

$$E_{6300} = \frac{A_{6300}\left(K_D + \dfrac{A_{5577}}{A_S}K_S\right)}{(A_D + S_D n(N_2))} \cdot \frac{\gamma_1 n(O_2) n(e)}{\left(1 + \dfrac{\gamma_1 n(O_2)}{\alpha_1 n(e)} + \dfrac{\gamma_2 n(N_2)}{\alpha_2 n(e)}\right)}, \tag{5}$$

where A_D, A_S, A_{5577} and A_{6300} are the corresponding Einstein level and transition coefficients for $O(^1D)$ (0·0091 sec^{-1}), $O(^1S)$ (1·36 sec^{-1}), the 5577 Å green line (1·28 sec^{-1}) and the 6300 Å red line (0·0069 sec^{-1}) respectively, $n(X)$ is the number density for species X,

K_D is the number of excitations per recombination for $O(^1D)$, and K_S is the number of excitations per recombination for $O(^1S)$. The rate coefficients used in this analysis are $\alpha_1 = 2{\cdot}6 \times 10^{-7}$ cm³/sec and $\alpha_2 = 3{\cdot}5 \times 10^{-7}$ cm³/sec both at 300°K with a $1/T$ dependence (Whitten and Poppoff, 1965), $\gamma_1 = 2 \times 10^{-11}$ cm³/sec at 300°K with a $1/T^{1/2}$ dependence and $\gamma_2 = 2 \times 10^{-12}$ cm³/sec (Ferguson, 1967) and $S_D = 5 \times 10^{-11}$ cm³/sec⁻¹ is the collisional deactivation coefficient for quenching by N_2 (Hunten and McElroy, 1966; McGrath and McGarvey, 1967).

Using the method of Bates (1959) and Walker (1965) the neutral temperature profile and number density profile of various neutral species were calculated by assuming that the measured night-time ion temperature at 325 km in Evans' data is equal to the neutral exospheric temperature. This assumption is valid for the night-time ionosphere and has been verified experimentally by Nisbeth (1967) and theoretically by numerous authors (Geisler and Bowhill, 1965; Nagy and Walker, 1967; Rees, Walker and Dalgarno, 1967; Banks 1966, 1967; Dalgarno, McElroy and Walker, 1967).

The number of excitations per recombination for $O(^1D)$ and for $O(^1S)$ are not well known, in this study the ratio of K_S/K_D is taken to be 0·2 (Hays and Walker, 1966) and our results are normalized to $K_D = 1{\cdot}0$.

From Evans' 1964 data for the night-time variation of the electron density profile, and the exospheric temperature (set equal to the measured ion temperature at 325 km) the night-time variation in the total emission in Rayleighs is obtained by integrating Equation (5) with respect to height. The night-time averages for the arbitrarily selected months of January, April, July and November 1964 are shown in Fig. 1. Since Evans' data for the

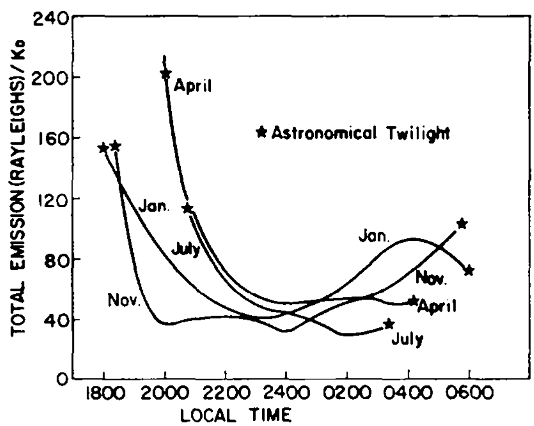

FIG. 1. NIGHT-TIME 6300 Å INTENSITY VARIATIONS FOR JANUARY, APRIL, JULY and NOVEMBER 1964.

electron density start at 200 km, a logarithmic extrapolation to 150 km was used in order to cover the effective emission range. We note that if K_D is taken to be 0·1 (Rees, Walker, and Dalgarno, 1967), the calculated total emission rate is very low compared to most of the previous experimental data quoted in the literature which indicates the total 6300 Å nightglow emission to be about 50–100 R (Chamberlain, 1961; Wallace and McElroy, 1966; Peterson and Steiger, 1966). Broadfoot and Kendall (1967) obtained a nightglow intensity of only 10 R which they considered very weak. Comparison of our calculations with these experimental results indicate that the number of excitations of $O(^1D)$ per recombination of O_2^+ is likely to be in the range

$$0{\cdot}2 < K_D < 1{\cdot}0.$$

The doppler profile of $O(^1D)$ atoms is Gaussian with a half-width determined by the neutral gas temperature due to its long lifetime and the particularly rapid thermalization resulting from excitation exchange with $O(^3P)$ (Hays and Walker, 1967). As a result, the 6300 Å photon is emitted with a doppler broadened line shape corresponding to the neutral

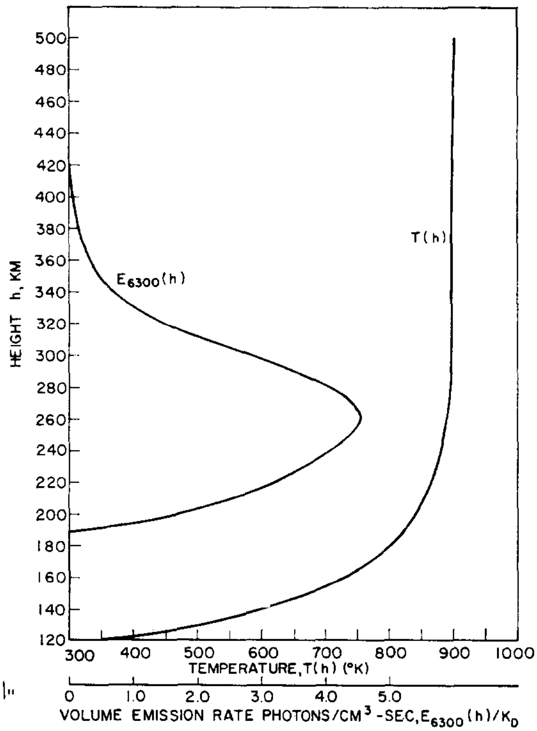

FIG. 2. NEUTRAL TEMPERATURE AND 6300 Å VOLUME EMISSION PROFILES FOR 2400 JANUARY 1964.

temperature at the emitting height. When the 6300 Å line is observed from the ground its integrated line shape is

$$I(\sigma - \sigma_0) = 1{\cdot}315 \times 10^6 \frac{\sqrt{M}}{\sigma_0} \int_0^\infty E_{6300}(h) \frac{\exp\left\{-5{\cdot}4 \times 10^{12} \dfrac{(\sigma - \sigma_0)^2 M}{\sigma_0^2 T(h)}\right\}}{\sqrt{(T(h))}} \, \mathrm{d}h, \quad (6)$$

where M is the molecular weight of atomic oxygen, σ_0 is the central wavelength in cm^{-1}, σ is an arbitrary wavelength in cm^{-1}, $T(h)$ is the neutral temperature at height h, and $E_{6300}(h)$ is the volume emission rate given in Equation (5). Figure 2 shows the calculated neutral temperature profile and 6300 Å volume emission rate at 2400 January 1964. It is seen that the major portion of the radiation occurs near the isothermal region of the atmosphere and therefore the integrated line shape departs only slightly from a Gaussian line shape. The night-time variation of the effective temperature based on the width of the line at half height, S

$$T_{\text{eff}} = 1{\cdot}95 \times 10^{12} \frac{MS^2}{\sigma_0^2} \quad (7)$$

is shown in Figs. 3 and 4 for four selected months in 1964. It is seen that the effective temperature obtained from doppler profile measurements follows closely the exospheric

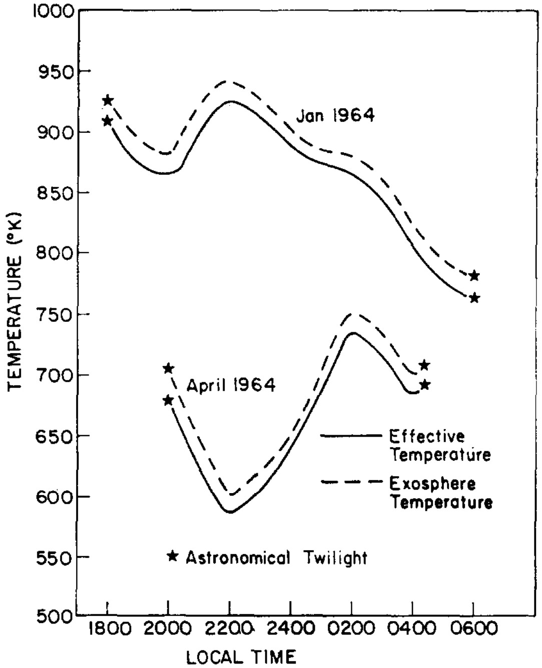

FIG. 3. EFFECTIVE DOPPLER AND EXOSPHERIC NIGHT-TIME TEMPERATURE VARIATIONS FOR JANUARY AND APRIL 1964.

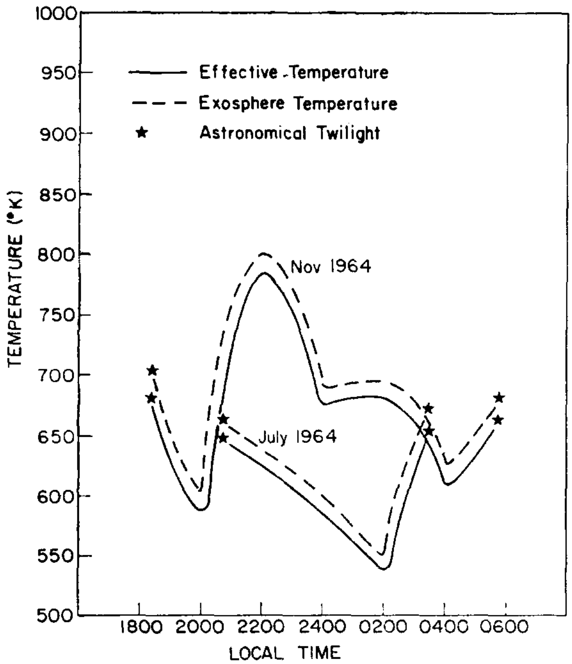

FIG. 4. EFFECTIVE DOPPLER and EXOSPHERIC NIGHT-TIME TEMPERATURE VARIATIONS FOR JULY AND NOVEMBER 1964.

temperature variation throughout the night at a value of 25–50°K lower in most cases. These results indicate that the neutral exospheric temperature can be obtained by monitoring the 6300 Å doppler temperature in the *F*-region.

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