

CONTAMINATION OF GROUND-BASED MEASUREMENTS OF OI (6300 Å) AND NI (5200 Å) AIRGLOW BY OH EMISSIONS

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Abstract—High resolution spectra of the 6300 Å and 5200 Å regions of the night sky have been obtained using a 1 m spectrometer. Typical errors in measurements of O(¹D) 6300 Å and N(²D) 5200 Å intensities due to contamination by overlapping OH emissions have been calculated for a fixed-filter photometer, a tilting-filter photometer and a spectrophotometer. The importance of careful selection of certain instrumental parameters in order to minimize measurement errors is emphasized.

1. INTRODUCTION

The forbidden transitions of atomic oxygen and atomic nitrogen, 6300 Å (O¹D → O³P) and 5200 Å (N²D → N⁴S), are weak airglow emissions that can provide valuable insight into the nighttime behaviour of the *F* region. However, the OH airglow emission in the mesosphere poses serious contamination problems for the accurate measurement of any airglow emission by optical ground-based instruments limited to a spectral resolution of a few Angstroms. The airglow atlas of Broadfoot and Kendall (1968) illustrates the great proliferation of the OH molecular bands throughout the night sky spectrum. The high resolution spectra obtained by Hernandez and Turtle (1969) and Hernandez (1974) document for 5200 Å and 6300 Å, respectively, the nature of this contamination. However, it is difficult to judge from these spectra the extent of the OH contamination.

For a Fabry-Perot interferometer, there may be as many as 25 orders within the transmission passband of the interference filter used as a monochromator to isolate the spectral feature of interest. Each order contains the contaminating OH rotational line and the *F* region airglow feature, but the intensity of each varies according to the order, and depends upon the filter transmission of the airglow line at the wavelength of the order being scanned. The wavelength of the filter passband is chosen to optimize the transmission of the *F* region airglow feature and to minimize the OH airglow contamination by attenuation. Therefore, the true intensity of the OH component is often not obvious from Fabry-Perot spectra. Furthermore, unless one also knows the number of orders separating the OH component from the *F* region feature, it is not possible to determine from a Fabry-Perot spectrum the wavelength of the OH line, but only its relative separation from the *F* region airglow line within one order. Therefore, the high resolution Fabry-Perot spectrum does not provide a useful display of the OH contamination in either wavelength or intensity.

The seriousness of the OH contamination problem and the difficulty it presents in the accurate determination of the 5200 and 6300 Å airglow intensities have been known for many years. While the problem is not so serious as to preclude the use of the instruments most commonly employed, which are fixed-filter photometers, tilting-filter photometers and spectrophotometers, this problem does require a careful study (with a monochromator) of the instrumental transmission as a function of wavelength. Although this may seem obvious, we feel that little attention in recent years has been given to this aspect of airglow observations. Papers have been pub-

lished concerning airglow observations that give no discussion of a particular instrument's ability to reject the OH contamination. To remind everyone that this OH contamination problem still remains, we show spectra of the 5200 and 6300 Å spectral regions with a resolution of approximately 1.5 Å. These permit unambiguous assessment of the OH contamination with respect to wavelength and intensity.

We use these values of OH intensity to determine the error of intensity measurements for both 5200 and 6300 Å as a function of instrumental bandwidth and the intensity of the *F* region airglow emission. From this study we conclude that for the 5200 Å spectral feature the OH contamination is very serious and may never be ignored. We find that measurements of 6300 Å intensities can be attained with errors less than 10% if the instrumental bandwidth is less than 5 Å and if the 6300 Å intensity is greater than 20 R.

2. OH CONTAMINATION OF 6300 Å MEASUREMENTS

Figure 1 is a zenith spectrum of the 6300 Å region obtained after integration for 90 min at Arecibo at a time when the 6300 Å intensity was fairly low (33 R). The instrument used was a 1 m Ebert-Fastie spectrophotometer at a spectral resolution of 1.5 Å. This figure shows the P₁(3), P₂(3) and the P₁(2) rotational components of the OH 9-3 band to be present with intensities of 4.9, 2.6 and 4.2 R, respectively. In Table 1 these results are seen to be comparable with those reported by Hernandez (1974).

The spectral features shown in Fig. 1 were convolved with a number of different instrumental transmission profiles. For the fixed-filter and the tilting-filter photometer simulations, the transmission curve of an interference filter was assumed to be Gaussian, i.e.

$$T_{\lambda} = T_0 \exp \frac{-2.77(\lambda - \lambda_0)^2}{B^2}, \quad (2.1)$$

where λ_0 is the peak wavelength, T_0 the peak transmission and B the bandwidth at 50% transmission.

From the synthetic spectra resulting from the convolution the fractional error in any 6300 Å measurement was calculated using,

$$\epsilon = (R - R')/R', \quad (2.2)$$

where R and R' are the observed peak signals when the OH intensities are non-zero and equal to zero respectively.

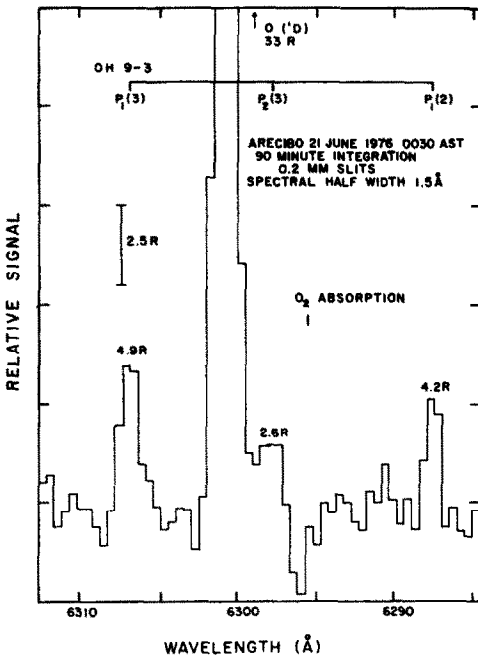


FIG. 1. HIGH RESOLUTION ZENITH SPECTRUM OF THE 6300 Å REGION OBTAINED WITH THE ONE METRE EBERT-FASTIE SPECTROPHOTOMETER BY THE SUMMATION OF 570 SCANS.

The error curves shown in Fig. 2(a) apply to a fixed-filter photometer with a filter centred at 6300.3 Å. The same set of curves also apply to the case of a tilting-filter photometer using a filter positioned with zero tilt angle at 6300.3 Å. However, in the tilting-filter system, when the filter is tilted the photometer will scan through the P₂(3) and P₁(2) OH lines, leading to a possibility of error in the determination of the background level. This error should be minimized by measuring the background at a wavelength well removed from that of any OH emissions. For the same reason the background measurement should not be made in the region of the 0-2 O₂(b' Σ_g⁺-X³ Σ_g⁻) absorption band located near 6295 Å (Curcio *et al.*, 1964). The same method was used to examine the OH contamination errors when a spectrophotometer replaces

TABLE 1. EMISSIONS IN THE 6300 Å REGION

Transition	Wave-length (Å)*	Typical intensity (R)	Measured intensity (R)‡
OH (9-3), P ₁ (2)	6287.4	5.75†	4.2
OH (9-3), P ₂ (3)	6298.0	2.0-4.0*	2.6
OI (³ P ₂ - ¹ D ₂)	6300.3	variable	variable
OH (9-3), P ₁ (3)	6306.8	5.0-8.0*	4.9

*From Hernandez (1974).

†Estimated from typical relative intensities.

‡Arecibo 1 m spectrometer.

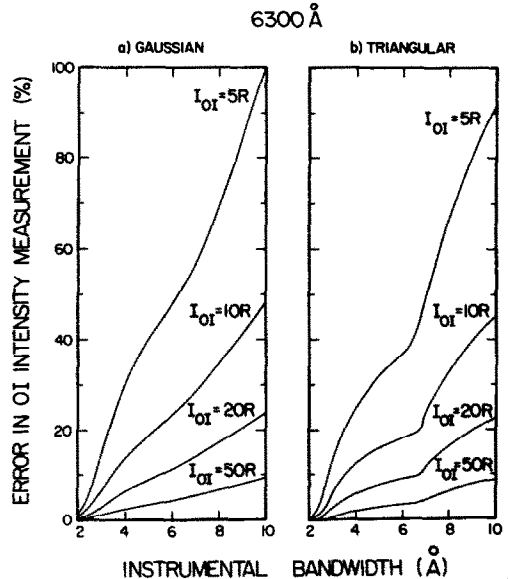


FIG. 2. THE OH CONTAMINATION ERRORS OF 6300 Å INTENSITY MEASUREMENTS AS A FUNCTION OF INSTRUMENTAL BANDWIDTH ASSUMING (a) A GAUSSIAN TRANSMISSION PROFILE (FILTER PHOTOMETER) AND (b) A TRIANGULAR PROFILE (SPECTROPHOTOMETER).

The error curves corresponding to 4 different values of O(¹D) intensity are shown.

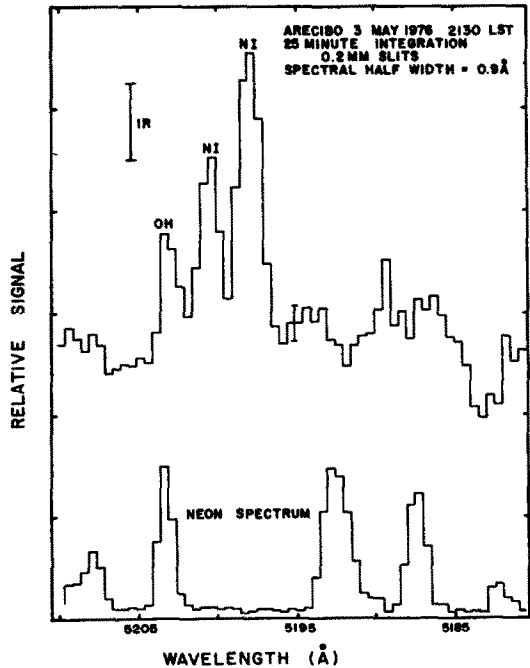


FIG. 3. HIGH RESOLUTION SPECTRUM OF THE 5200 Å REGION PRODUCED BY THE SUMMATION OF 180 SCANS.

The one metre spectrometer was oriented westwards at 60° zenith angle. A neon wavelength calibration spectrum is also shown.

the interference filter. For this case the instrumental transmission was represented by a triangular function given by,

$$T_{\lambda} = T_0 - \left\{ \frac{T_0 |\lambda - \lambda_0|}{B} \right\}, \quad |\lambda - \lambda_0| \leq B$$

and

$$T_{\lambda} = 0, \quad |\lambda - \lambda_0| > B. \quad (2.3)$$

The magnitude of the OH contamination error is slightly reduced when a triangular transmission function is assumed. The error curves shown in Fig. 2(b) apply to scanning spectrometer measurements.

3. OH CONTAMINATION OF 5200 Å MEASUREMENTS

Figure 3 is a spectrum of the 5200 Å region at a spectral resolution of 0.9 Å obtained at Arecibo with a one metre Ebert-Fastie spectrophotometer during late evening twilight. The integration time required was 25 min and the elevation angle was 30°. The intensities of the OH $Q_1(1)$ line at 5202.8 Å and the $N(^2D)$ doublet components at 5200.4 Å and 5198.1 Å are 1.7, 2.7 and 4.1 R, respectively. The branching ratio of the two components of the $N(^2D)$ doublet is 1.52 ± 0.1 which agrees with the theoretical value of 1.56 (Garstang, 1956) and the experimental value of 1.56 ± 0.1 (Hernandez and Turtle, 1969). Some components of the R branch of the OH 9-2 band near 5190 Å can also be seen. In the course of a night's observations the ratio between the $N(^2D)$ doublet intensity and the $Q_1(1)$ OH line at Arecibo has been observed to change, being between 5 and 10 at evening twilight, between 2 and 5 during any nighttime enhancements such as the post-midnight collapse, and of the order

of 1 or lower at other times. Therefore, our simulation analysis of the error introduced by OH contamination includes several values for this ratio to encompass the range of error that might be present in 5200 Å airglow observations on any one night.

(a) The fixed-filter system

As a typical example, the errors which may result from the use of a filter centred at 5200.0 Å are shown in Fig. 4(a). However, this would not be a good choice because a larger signal due to the $N(^2D)$ doublet would be measured by a filter centred at a wavelength of 5199.0 Å. However, by centering the filter on the stronger $N(^2D)$ line at 5198.1 Å, the magnitude of the OH contamination could be reduced even further. When this is done the errors are as shown by the dashed curves in Fig. 4(a). It should be noted that if narrow filters are used, account must be taken of the fact that the filter will probably not transmit both lines of the $N(^2D)$ doublet at the same transmission. This effect must be included in the data reduction formulae.

(b) The tilting-filter system

One method of reducing tilting-filter data is to measure the signal at the peak which is sometimes observed when the filter scans through the 5200 Å region. In order to carry out an error analysis we have assumed a filter positioned at 5200.4 Å for zero tilt angle with a peak transmission that drops linearly with the wavelength shift to 70% of its maximum value at 5198.1 Å. We have also assumed that the product of peak transmission and bandwidth remains constant, so that the bandwidth increases by 43% over this region. Filter passbands for different

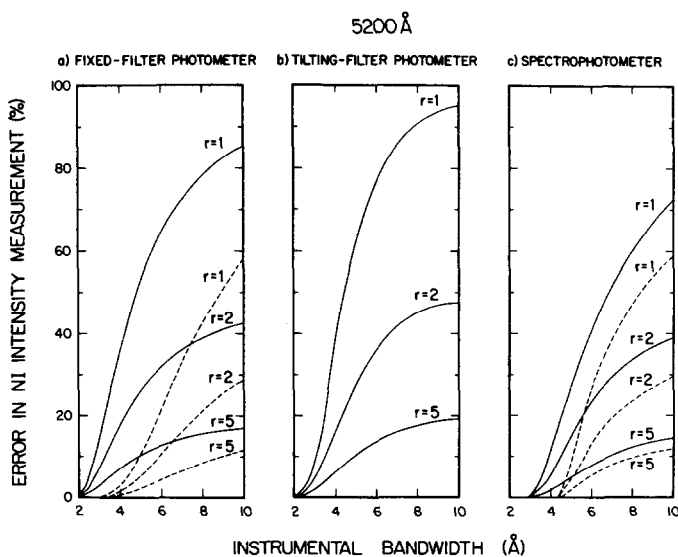


FIG. 4. THE 5200 Å INTENSITY CONTAMINATION ERROR AS A FUNCTION OF INSTRUMENTAL BANDWIDTH FOR THREE INSTRUMENTS: (a) A FIXED-FILTER PHOTOMETER USING A FILTER CENTRED AT 5200.0 Å (FULL CURVES) AND 5198.1 Å (DASHED CURVES), (b) A TILTING-FILTER PHOTOMETER AND (c) A SPECTROPHOTOMETER EMPLOYING THE METHOD OF READING THE PEAK SIGNAL (FULL CURVES) AND READING THE SIGNAL AT A FIXED WAVELENGTH (DASHED CURVES).

The quantity "r" is the ratio of the $N(^2D)$ doublet intensity to the OH $Q_1(1)$ intensity.

values of the wavelength shift were convolved with the $N(^2D)$ emission spectrum in order to determine the wavelength at which the maximum signal would be observed. This wavelength is found to be a function of bandwidth which converges to 5200.4 Å as the flat-position bandwidth approaches 10 Å.

Because the maximum signal occurs at a filter wavelength closer to the OH line than in the case of the 5198.1 Å fixed-filter method, OH contamination produces a larger error in this tilting-filter system, as shown in Fig. 4(b). It should be appreciated that this particular case has been chosen as a typical example only. The magnitude of the OH contamination error is closely dependent on the variation in filter parameters with tilt angle, necessitating separate calculations of the error for every unique case. We note that even more serious errors could occur if the filter scan starts above 5203 Å. When the OH/ $N(^2D)$ ratio is high, the wavelength of maximum signal may be closer to the OH line than the $N(^2D)$ doublet. When the filter is tilted in order to determine the background signal the R components of the OH 9-2 band near 5190 Å may be observed. A background measurement near this wavelength should be avoided.

(c) *The scanning spectrometer system*

For a spectrometer the instrumental function is triangular and the spectral halfwidth and transmission function are independent of wavelength over the narrow region of interest. In Fig. 4(c) we show the OH contamination errors resulting from two methods of scaling the spectrum. The full curves result if the peak reading is always used, irrespective of the wavelength at which it occurs. These results are not very useful when both the spectral width and OH/ $N(^2D)$ ratio are high, because the peak wavelength is observed near the OH wavelength of 5202.8 Å. The results of the other method, the case in which the reading was always made at 5198.1 Å regardless of the position of the peak signal, are shown by the dashed set of curves in Fig. 4(c).

4. DISCUSSION

We conclude from Fig. 2 that filter photometry of the 6300 Å nightglow to an accuracy of 10% is generally possible if the filter bandwidth is less than 5 Å. However, considerable care must be taken in interpreting 6300 Å intensities which are observed to be less than 20 R. The simultaneous use of a filter centred on a strong OH line in the 9-3 band would enable the variability of the OH contamination to be assessed and a correction to be made.

It follows from Fig. 4 that the fixed-filter method could be used for 5200 Å work, if the filter bandwidth were 4 Å or narrower. However, elaborate precautions would have to be taken to prevent a drift in the filter centre wavelength.

We recommend the calibration of the transmission profile of the filter by a monochromator on each night of observation to ensure accurate knowledge of the peak wavelength and bandwidth of the filter. Nevertheless, the errors introduced by using a different filter to measure the background level make this method a poor choice for accurate quantitative work on the $N(^2D)$ doublet.

The tilting-filter method allows a more accurate background subtraction, but for measurements of the 5200 Å emission, the blending of the $N(^2D)$ doublet components with the OH $Q_1(1)$ rotational line, coupled with the change in filter characteristics with tilt angle, makes the data reduction a complicated task. Apart from during the post-twilight decay and periods of marked intensity enhancement of the $N(^2D)$ emission, the potential errors in tilting-filter photometry of the 5200 Å doublet would suggest that this method is unsuitable for accurate work.

By using a scanning spectrophotometer of the Ebert-Fastie type with a resolution better than 3 Å the error due to OH contamination becomes negligible. As the temporal resolution of the Arecibo one metre spectrometer is almost comparable with that of most filter photometers we believe this type of instrument to be the best choice for accurate quantitative ground-based measurements of the 5200 Å nightglow.

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