Twilight Transition Spectra of Atmospheric O2 IR Emissions

Doran Baker  
*Utah State University*

Allan Steed  
*Utah State University*

Ronald Huppi  
*Utah State University*

Kay Baker  
*Utah State University*

Follow this and additional works at: https://digitalcommons.usu.edu/sdl_pubs

**Recommended Citation**

https://digitalcommons.usu.edu/sdl_pubs/6

This Article is brought to you for free and open access by the Space Dynamics Lab at DigitalCommons@USU. It has been accepted for inclusion in Space Dynamics Lab Publications by an authorized administrator of DigitalCommons@USU. For more information, please contact digitalcommons@usu.edu.
Abstract. Resolved spectra have been obtained from the ground of the $O_2(\alpha^1A_g)$ emissions from the upper atmosphere utilizing a wide-field interferometer with a cryogenically cooled germanium detector. The rotational structure of both the (0,0) band at 1.27 μm and the (0,1) band at 1.58 μm are clearly separable from the hydroxyl airglow. The decay rate of the $O_2(\alpha^1A_g)$ during the twilight transition has been observed.

$O_2$ IR Atmospheric Band Airglow

The metastable excited state ($\alpha^1A_g$) of molecular oxygen is of considerable importance in aeronomical processes. The state is particularly interesting because its long lifetime of 3.8 x 10^3 seconds [Badger et al., 1965] makes its 0.98 eV of excitation energy available in atmospheric interactions of many types. These interactions include ionization and charge transfer in addition to photochemical reactions. The high throughput of the wide-field infrared interferometer-spectrometer has made it possible to resolve the spectrum of the infrared atmospheric emission bands of $O_2$ at 1.27 and 1.58 μm. These bands originate from transitions from the $v' = 0$ energy level of the $\alpha^1A_g$ state to the $v'' = 0$ and $v'' = 1$ levels of the ground state $X^3Z^+$.

Extensive radiometric observations of this infrared atmospheric band system have been made as summarized in the fine review articles of Evans and Llewellyn (1970) and Vallance Jones (1973). The $O_2(0,1)$ infrared atmospheric band at 1.58 μm was first discovered in the twilight airglow by Vallance Jones and Harrison (1958) using a grating spectrometer; they observed this band as an asymmetry, which decayed during twilight, in the spectral profile of the Q branch of the (4,2) band of the hydroxyl airglow.

The $O_2(0,0)$ band at 1.27 μm has been observed in laboratory experiments [Whitlow and Findlay, 1967; Becker et al., 1971] a factor of 500 times brighter than the $O_2(0,1)$ band at 1.58 μm. However, unlike the situation at 1.58 μm, the atmospheric absorption at 1.27 μm is severe [Evans et al., 1970]. In fact, the first identification of the ($\alpha^1B_g - X^3Z^+$) electronic transition in $O_2$ was first identified by Herzberg (1934) from observing the strong terrestrial atmospheric absorption of the solar spectrum at 1.27 μm.

Apparently, the $O_2$ 1.27-μm band was first detected (but not identified) by Gopphathoe and Kiektal [1965] on a daytime balloon flight. Positive identification of this band was made in the day and twilight airglow by Noxon and Vallance Jones (1962) who flew a grating spectrometer aboard an aircraft. The (0,0) band at 1.27 μm was first resolved from the ground by Lowe (1969) who used a standard Michelson interferometer.

Observational Technique

The twilight-airglow spectra of the $O_2$ infrared atmospheric system obtained by Utah State University resulted from using a field-widened interferometer-spectrometer developed under grants from the National Science Foundation [No. GA 786] and the Air Force Cambridge Research Laboratories. Two small-angle compensating wedge prisms are used in such a way that incident light rays which may be at oblique as 6 degrees are still accepted by the interferometer even when driven to high resolution. The back surface of the prism is reflective and serves as the end mirrors of the interferometer. The change of optical path difference to obtain an interferogram is accomplished by driving one of the prisms parallel with its apparent mirror position [Despain et al., 1971]. This instrument uses an electromagnetically driven, gas-lubricated, precision platform for the movable prism. The details of the instrument have been reported elsewhere [Despain et al., 1974].

The detector used for this study was an intrinsic-germanium photoconductor operated at liquid-nitrogen temperature (77°K). The optics of the interferometer were operated at ambient temperature. The interferometer-spectrometer was calibrated using a controlled blackbody source.

Interferograms from the spectrometer were fed into the data system of the USU Argus aeronomy observatory. Analog-to-digital (A/D) conversions were made, and fast Fourier transforms (FFT) were computed in near real time as the interferograms were generated.

Figure 1. Zenith spectral radiance at Logan, Utah at 02:19 hrs UT (19:19 hrs local) on September 5, 1975. Spectral resolution = 5 cm⁻¹; observing time = 1½ min.; viewing field = 0.02 sr. [The instrument response function is normalized to 1.27 μm, to obtain the kR/cm⁻¹ of the spectrum of any other wavelength divided by the relative instrument response (right-hand scale) at that wavelength.]
The near-infrared interferometer-spectrometer was operated to observe the airglow from a location at Logan, Utah, on September 5, 1974, local time. The latitude of this observing site is 41°44'34" North, the longitude is 111°48'24" West, and the elevation is 4790 feet above sea level.

Figures 1 and 2 show the overhead (zenith) spectral radiance at two different times during the evening twilight. The spectral coverage is from 1.1 through 1.7 μm. The optical resolution of each reduced spectrum is 3 cm⁻¹, and the total observing time to obtain the spectrum was 15 minutes. Four 15-second transformed interferograms were signal averaged (coadded) to obtain each of the two spectrograms shown. In each case, the viewing aspect was the geometrical zenith with the spectrometer operated in this case at a 9-degree full angle field-of-view. A two-channel radiometer was used to obtain the absolute zenith radiance in selected wavelength bands for continuous monitoring and calibration purposes. One filter was used to measure the radiance of the (0,0) band of O₂(Δv=0); a second was used to monitor that part of the Δν = 2 band sequence of OH between 1.57 and 1.70 μm.

The spectrum of the O₂(Δv=2) (0,0) band during the twilight transition from day to night is shown in more detail in Figure 3. The decay of the O₂(0,0) band at 1.27 μm relative to the surrounding OH bands is clearly evident. At a longer wavelength is the (8,5) band of the OH Meinel sequence, and at a shorter wavelength is the OH(7,4) band. The Q rotational lines of these bands are indicated on Figure 4. The sequence of spectra of Figure 4 are the same twilight transition shown with an expanded ordinate.

Discussion

The dominant twilight airglow emission species in the 1.1 to 1.7-μm spectral region, in addition to the O₂(Δv=2) infrared atmospheric system at 1.27 and 1.58 μm (Figure 1), are the first and second overtone rotation-vibration band sequences (Meinel X^2Π_g - X^2Π_u) of the ground electronic state of the hydroxyl (OH) molecule. In spite
of the atmospheric extinction [Selby and McCatchey, 1972; Baker et al., 1973], clearly evident from left to right in Figure 1, are the \((4,2)\), \((3,1)\), and \((2,0)\) bands of the \(\Delta \nu = 2\) sequence and the \((8,5)\), \((7,4)\), and \((6,3)\) bands of the \(\Delta \nu = 3\) sequence. The location of the Q lines are indicated on the figures for each of these bands.

The \(\text{O}_2(0,0)\) band (whose dominant line is at 1.268 \(\mu\)m) occurs to the right of the Q line of the \(\text{OH}(8,5)\) band at 1.290 \(\mu\)m. Since the R rotational lines of the \(\text{OH}(8,5)\) band overlay directly on the \(\text{O}_2(0,0)\) band, it is evident that exceptional care must be exercised in using fixed bandpass filter radiometers to study \(\text{O}_2(aXAg)\) airglow. Valid conclusions drawn about the variations and enhancements of \(\text{O}_2(aXAg)\) emissions based only upon radiometric measurements are difficult to achieve.

In the first spectrum of Figure 4, the \(\text{OH}\) and the \(\text{O}_2\) IR emissions can be seen superimposed upon the spectrum of the scattered sunlight as seen through the absorbing lower atmosphere. The subsequent spectra through the twilight transition clearly show the decay of the \(\text{O}_2(0,0)\) emissions from the high daytime levels. A detailed analysis must, of course, take into account the extinction due to absorption and scattering of the lower layers of atmosphere [Evans et al., 1970]. However, the apparent radiances of the \(\text{O}_2(0,0)\) band observed from the ground in the zenith at various times during the twilight transition is given in Table 1. The effective decay time constant of the decay simply modeled as an exponential is about 61 minutes.

Figure 5 shows the twilight transition behavior of the \((0,1)\) Q line \(\text{O}_2(a^1\Delta_g)\) at 1.582 \(\mu\)m. This line lies immediately to the right of the \(\text{OH}(4,2)\) Q line at 1.583 \(\mu\)m; however, its decay relative to the \(\text{OH}\) can clearly be distinguished. The effective decay time constant of the \(\text{O}_2(0,1)\) appears to be 56 minutes. Part of the remainder of the rotational structure of the \(\text{O}_2(0,1)\) band can be delineated immediately after the solar scattering diminishes.

**Table 1. Zenith radiant of \(\text{O}_2(a^1\Delta_g)\) as observed from the ground at Logan on Sep 5, 1974**

<table>
<thead>
<tr>
<th>Universal Time</th>
<th>Earth Shadow Radiance</th>
<th>Apparent Radiance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(hrs:min)</td>
<td>(km)</td>
</tr>
<tr>
<td>02:52</td>
<td>95.7</td>
<td>104</td>
</tr>
<tr>
<td>03:45</td>
<td>361.5</td>
<td>45</td>
</tr>
<tr>
<td>04:30</td>
<td>703.0</td>
<td>35</td>
</tr>
<tr>
<td>05:35</td>
<td>1343.0</td>
<td>17</td>
</tr>
</tbody>
</table>

**Figure 5. Zenith spectra of the atmospheric solar scattering and airglow emissions around 1.58 \(\mu\)m during the twilight of September 5, 1975, at Logan from 02:13 to 05:35 hrs UT (19:13 to 22:35 hrs LST).**

Acknowledgments. This work was sponsored by the National Science Foundation under Grant No. GA 38794. The assistance of the staff members of Utah State University and the University of Alaska are acknowledged. Of particular mention are the contributions of Gerry Romick, Brent Bartschi, Gene Ware, Ralph Embry, Ralph Briscoe, Carla Clyde, and Ralph Haycock. The most beneficial assistance of A.T. Stair and Jim Ulwick of the Air Force Cambridge Research Laboratories is also very much appreciated.

**References**


Becker, K. H., W. Groth and U. Schurath, The ratio of the Franck-Condon factors \(q(0,0)/q(0,1)\) of the infrared atmospheric band system of oxygen, *Planetary Space Sci.*, 19, 1009, 1971.


Noxon, J.F., and A. Vallance Jones, Observation of the (0,0) band of the (1Δg-1Σg) system of oxygen in the day and twilight airglow, Nature, 196, 157, 1962.

(Received February 4, 1975; accepted March 28, 1975.)