3.3 8-13 MICRON OBSERVATIONS OF TITAN*

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Abstract

Narrow-band ($\Delta\lambda/\lambda \simeq 0.015$) observations of Titan at selected wavelengths in the 8-13 micron range show evidence for a strong temperature inversion and the existence of at least one more spectroscopically active component in the atmosphere in addition to H_2 and CH_4.

Introduction

Titan has recently been the object of numerous investigations, both observational and theoretical. This surge in interest has been primarily due to the detection of H_2 (Trafton 1972) and the observations of high brightness temperatures in the 8-20 micron range, the latter of which suggest that the atmosphere of Titan may be massive enough to produce a substantial greenhouse effect (Morrison, Cruikshank, and Murphy 1972). This paper describes observations of Titan in the range of 8-13 μm with a resolution $\Delta\lambda/\lambda \simeq 0.015$ and discusses some of the implications of these observations.

Observations

The observations reported here were obtained using a cooled filter-wheel spectrometer together with the UCSD-University of Minnesota 60-inch (152-cm) telescope on Mount Lemmon. The data acquisition and reduction have been discussed elsewhere (Gillett and Forrest 1973). The results are shown in Figure 3-1, where the observed surface brightness is plotted as a function of wavelength, assuming the radius of Titan to be 2.44×10^3 km (Allen 1963). The surface brightnesses are reduced by about 10 percent using the radius proposed for Titan by Morrison et al. (1973). Vertical bars indicate ±1 standard deviation of the mean of measurements at that wavelength, and the horizontal bars indicate the half-power bandpass of the filter used. Also included in this figure are broad-band measurements taken at various times, and curves of constant brightness temperature.

If the actual spectrum of Titan can be approximated by smooth curves joining the spectrometer data points, the 8.4-micron and 12.5-micron broad-band observations appear to be in good agreement with the spectrometer results; however, the 11-micron broad-band measurements seem to be high by a factor of about 1.5. This may indicate the existence of further structure in the spectrum between 10 and 12 μm.

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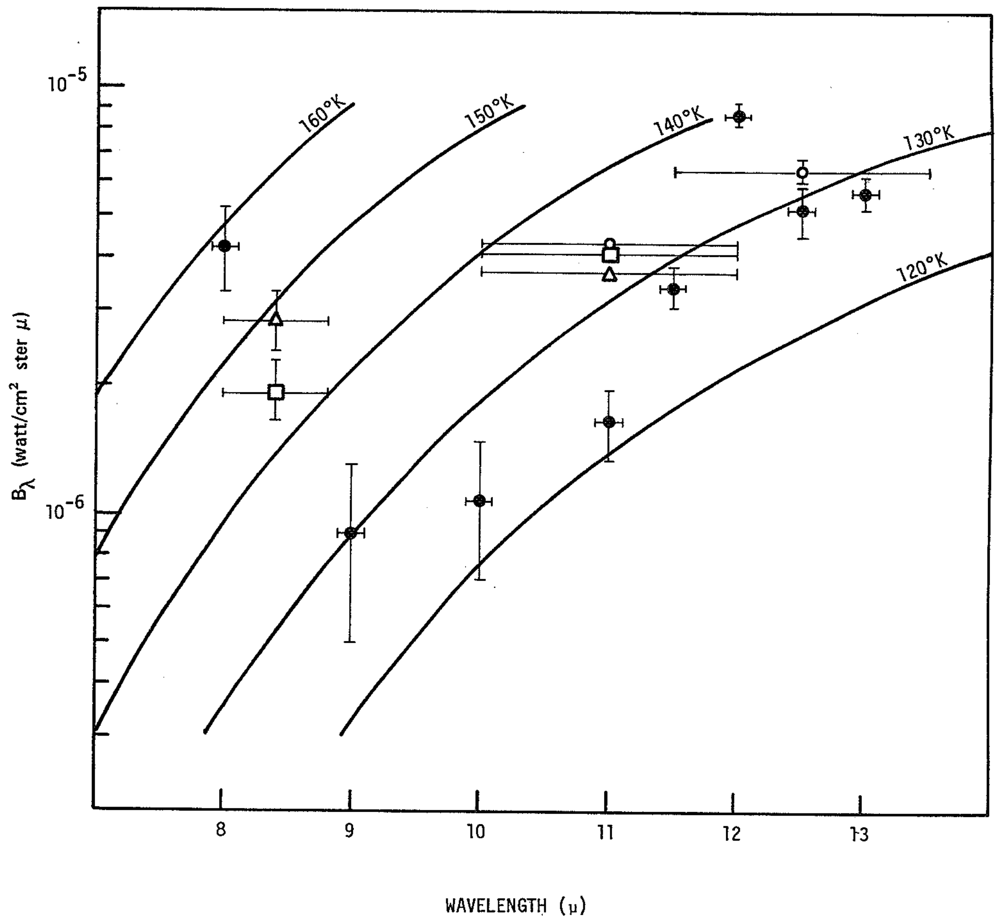

Figure 3-1. Surface brightness of Titan as a function of wavelength. Spectrometer observations: filled circles, 1/1/73 and 2/15/73. Broad-band observations: open circles, 1/1/73; open triangles, 9/29/72; open squares, 11/16/71. Horizontal lines indicate bandpass of filter used.

Discussion

The most significant features of these data are:

(1) The observations require the presence of at least one spectroscopically active component in addition to the previously detected H_2 and CH_4. If, in the levels where the 9-13 micron radiation originates, the temperature is decreasing with increasing height, then a strong absorber around 10 μm would be required to explain the temperature minimum near this wavelength. Such an absorber could be NH_3 with its ν_2 fundamental near 10.5 μm. The models calculated by Pollack (1973), including the effects of NH_3 absorption, give brightness temperatures in the NH_3 band of about 120°K which is consistent with the observations. On the other hand, if the radiation originates above a temperature inversion (as suggested by Caldwell, Larach, and Danielson 1973), then an additional radiator is required to explain the maximum in brightness temperature around 12 μm (probably C_2H_6). The wavelength coverage and statistical accuracy of the data presented here are not sufficient to rule out either of these possibilities;

(2) The high brightness temperature within the 7.7-micron CH_4 band shown by the measurement at 8.0 μm definitely indicates the presence of a temperature inversion. A similar elevated brightness temperature within the ν_4 fundamental of CH_4 has been found earlier in the spectrum of Jupiter (Gillett, Low, and Stein 1969), and its association with a temperature inversion was demonstrated by the detection of limb brightening at 7.9 μm (Gillett and Westphal 1973). A surprising aspect of the observations of Titan is the strength of this temperature inversion. The surface brightness of Titan at 8.0 μm is about 6 times that of Jupiter at the same wavelength and about 20 times that of Saturn. The most likely reason for this is that the CH_4/H_2 ratio is much larger for Titan than for Jupiter or Saturn, thus H_2 cooling of the upper atmosphere of Titan is much less effective. Another possibility is that the rate at which energy is absorbed per unit area in the upper atmosphere of Titan may be somewhat higher than for Saturn, depending on the mechanism producing the inversion, but this effect alone cannot account for the difference in the 8.0-micron surface brightness.

For the inversion on Jupiter it was suggested by Gillett *et al.* (1969) that the energy balance in the inversion layers was determined by absorption of solar radiation in the 3.3-micron band of CH_4 plus possibly some contribution in overtone bands, and radiation through the 7.7-micron CH_4 band and collision-induced transitions in H_2. For Titan it appears that the rate at which energy is being radiated from the upper atmosphere by the 7.7-micron CH_4 band alone, cannot be balanced by absorption of solar radiation via the 3.3-micron and 2.35-micron CH_4 bands. In fact, it is not clear whether the observed inversion could be maintained even if one considered all the overtone bands of CH_4.

A possible alternative source of energy for an inversion that does not suffer from this difficulty is the mechanism proposed by Caldwell *et al.* (1973), in which solid particles in the upper atmosphere absorb visual and ultraviolet radiation from the Sun and in turn transfer this energy to the gas through collisions. These authors have proposed that the elevated brightness temperatures in the 8-13 micron range reported earlier (Morrison *et al.* 1972) are due to emission from above a temperature inversion and predicted emission peaks at 7.7 μm (CH_4), 12.2 μm (C_2H_6) and 10.5 μm (C_2H_4). The data reported here show strong emission peaks in the 7.7-micron CH_4 band and at 12 μm. Unfortunately, no measurements were made at 10.5 μm.

Additional insight into the properties of Titan's atmosphere could be obtained from model calculations taking into account the observations reported here. Important additional observational data would include higher spectral resolution observations around 20 μm and better wavelength coverage in the 8-13 micron range.

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