3.4 STELLAR OCCULTATIONS

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Introduction

Stellar occultations provide a unique way of obtaining rigorous information on the composition and thermal structure of Titan's upper atmosphere. Although detailed predictions by Taylor (1973) indicate that no suitable occultations by Titan will occur during 1973 and 1974, statistical calculations by O'Leary (1972) predict about 2 "passable" occultations per year, and one "good" occultation every 5 years. A "passable" occultation involves an intensity drop of at least 10% in the U; for a "good" occultation the intensity drop exceeds 50% of the U.

No occultation by Titan has ever been observed photo-electrically. To indicate the kinds of information that potentially can be obtained from occultation light curves, we turn to some observations of the occultation of Beta Scorpii by Jupiter on May 13, 1971.

Atmospheric Structure from an Occultation Light Curve

Simultaneous light curves in three channels (0.353, 0.393, 0.620 μm) of the emersion of Beta Scorpii AB are shown in Figure 3-2 at a time resolution of 0.2 second (Veverka et al. 1973). These light curves can be "inverted" to yield refractivity profiles, and once an atmospheric composition is assumed, temperature and number density profiles such as those shown in Figure 3-3 can be obtained (Wasserman and Veverka 1973b).

An outstanding feature of the light curves shown in Figure 3-2 is the occurrance of numerous light flashes or "spikes", which can be interpreted as small fluctuations in the refractivity profile of the atmosphere. Similar spikes have been observed during an occultation by Neptune (Freeman and Lyngå 1970) suggesting that these fluctuations may be a characteristic of the upper atmospheres of all Jovian planets, and by extension, of Titan's as well. Note that the spikes in Figure 3-2 translate into wiggles in the temperature profile in Figure 3-3.

Atmospheric Composition from Spikes

Whenever high time resolution records of occultation events are obtainable simultaneously in several colors, wavelength dependent time delays in spike arrival times will be observed (Brinkmann 1971; Wasserman and Veverka 1973a). From the differences in spike arrival times at different wavelengths it is possible to determine the relative refractivity of the atmosphere at these wavelengths. Spike arrival delays were observed during the emersion of Beta Scorpii AB, for example, with observations taken every 0.01 second (Veverka et al. 1973). The time delays are well-defined and increase systematically with wavelength. Assuming that the Jovian atmosphere is well

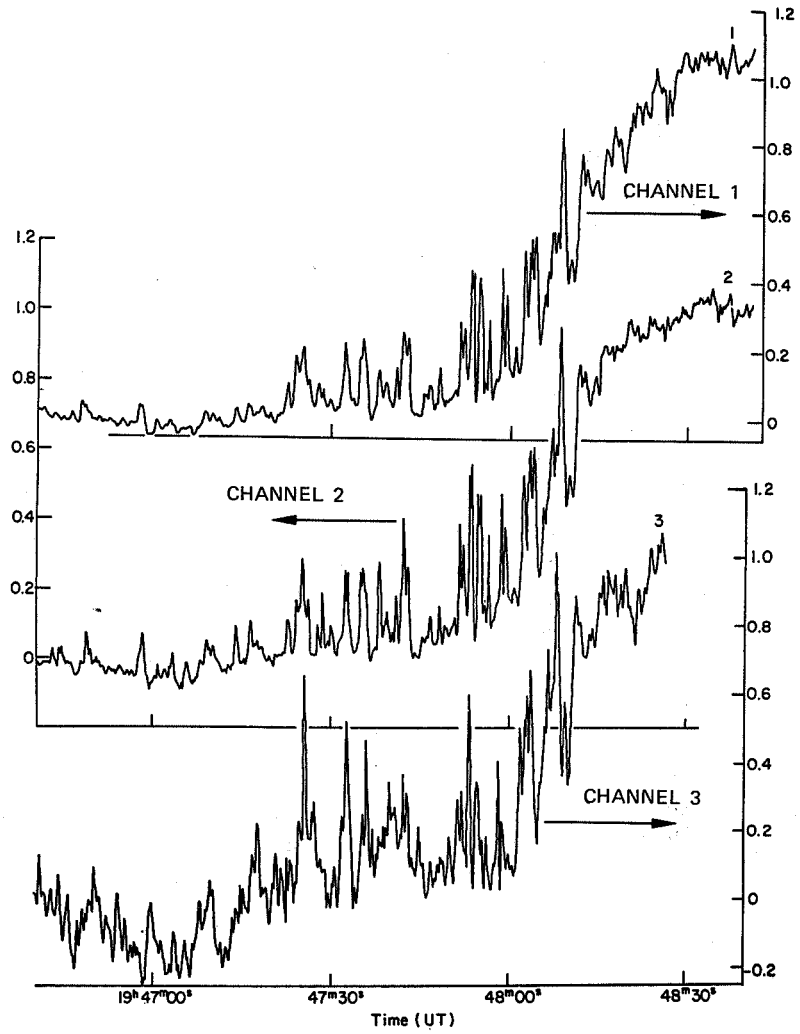

Figure 3-2. Emersion of Beta Scorpii AB in three channels (0.353, 0.393, 0.620 μm) at Δt = 0.2 sec. (Veverka et al. 1973). The zero level base-line was determined by averaging the output over several minutes at a point far removed from the time of emersion. The full scale level was determined by setting the star's full intensity equal to unity. After Veverka, et al. (1974). Reprinted from The Astronomical Journal, in press, with permission of The Astronomical Journal, Dr. L. Woltjer, Ed. All rights reserved.

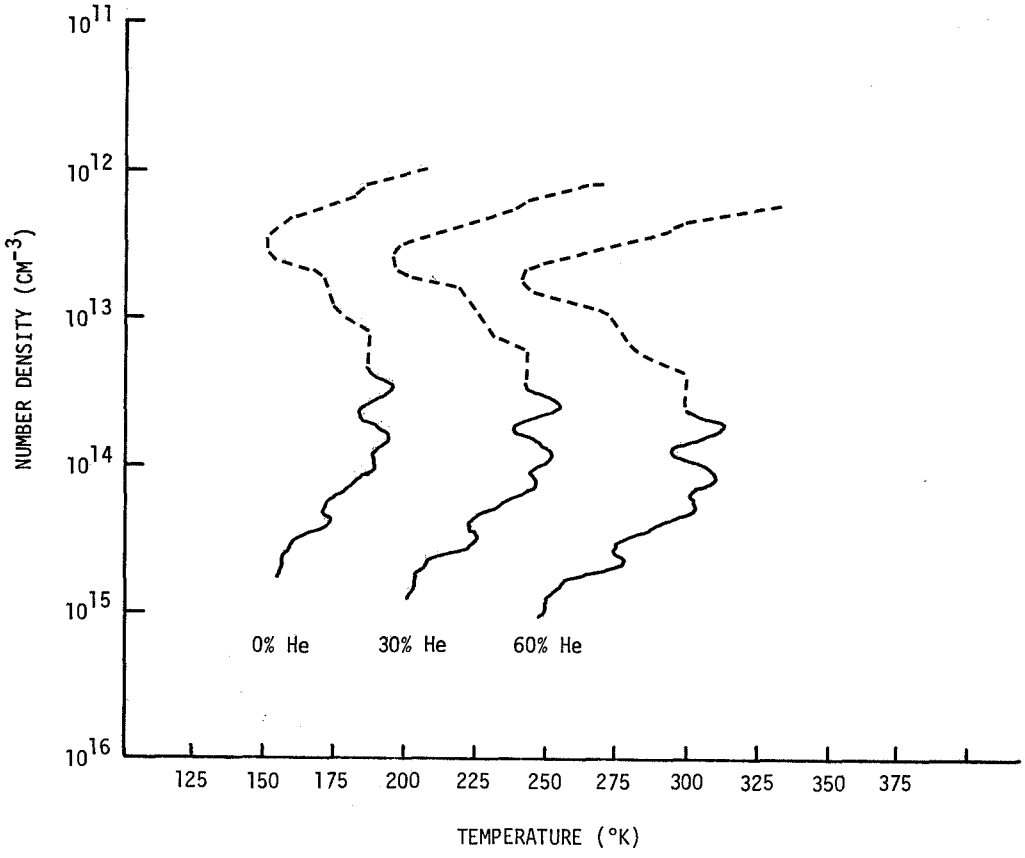

Figure 3-3. Temperature profiles derived from Channel 2 data for three assumed compositions of the Jovian atmosphere. Left to right: 0% He, 100% H_2; 30% He, 70% H_2; 60% He, 40% H_2 (by number). The upper portions of the profiles are uncertain and are therefore shown dashed (cf. Wasserman and Veverka 1973b). The bumps correspond to the spikes in the light curve. (Although not shown, the profiles derived from the other two channels are similar.) After Veverka et al. (1974). Reprinted from The Astronomical Journal, in press, with permission of The Astronomical Journal, Dr. L. Woltjer, Ed. All rights reserved.

mixed at this level and consists mostly of hydrogen and helium, Elliot et al. (1973) derive the relative abundance of these gases to be:

$$He/H_2 = 0.19^{+.35}_{-.19}$$

by number, which corresponds to a mean molecular weight of $2.32^{+.38}_{-.32}$.

Outlook for Titan

Even if spikes cannot be detected in light curves of occultations by Titan, reliable temperature/number density profiles will be determined if the atmospheric composition is assumed. A strong discrimination among composition models will be possible if an independent estimate of reasonable upper atmosphere temperatures exists. For simplicity, assume that an isothermal structure is found with T = 100°K for pure H_2. Since in this case $T \sim \mu$ (where μ is the mean molecular weight) we have the situation summarized in Table 3-1. It is easy to discriminate against compositions which give high μ's, and hence high temperatures. Thus in this case an atmosphere consisting of 50% of either CH_4 or N_2 could be excluded since it would imply temperatures >450°K. However, as Table 3-1 shows, it is difficult to discriminate against high helium fractions in this way.

Fortunately, timing of spike arrival times is most successful in detecting large helium concentrations. For example, it turns out that from the refractivity ratio:

$$\frac{\nu_2}{\nu_3} = \frac{\nu(3934\ \text{Å})}{\nu(6201\ \text{Å})}$$

that large amounts of He are easily detected in the presence of CH_4, N_2 or H_2, but large amounts of N_2 or CH_4 in the presence of H_2 (or vice versa) are not. The situation can be slightly improved by using a larger spread in wavelengths, or more than two wavelengths.

Summary

Stellar occultations can yield reliable temperature/number density profiles of Titan's upper atmosphere near the 10^{14} cm^{-3} number density level. The temperature profiles can be used to discriminate between atmospheric compositions having high mean molecular weights ($\mu > 5$), and those having low mean molecular weights ($\mu < 5$), as indicated in Table 3-1. Detection of spikes at several wavelengths with high time resolution can set useful limits on the helium content of the atmosphere.

Table 3-1. Temperature Dependence on Composition of Hypothetical Upper Atmospheres (See text for details).

CONSTITUENTS	COMPOSITION (BY NUMBER)	MEAN MOLECULAR WEIGHT	T (°K)
H_2 and He	100% H_2	2.0	100
	90% H_2 and 10% He	2.2	110
	50% H_2 and 50% He	3.0	150
H_2 and CH_4	90% H_2 and 10% CH_4	3.4	170
	50% H_2 and 50% CH_4	9.0	450
H_2 and N_2	90% H_2 and 10% N_2	4.6	230
	50% H_2 and 50% N_2	15.0	750
H_2, CH_4, and N_2	80% H_2, 10% CH_4, and 10% N_2	5.0	250
	50% H_2, 25% CH_4, and 25% N_2	12.0	600

It is therefore important that future occultations by Titan be predicted well in advance, and imperative that they be observed adequately. Such observations will also yield an accurate value of Titan's diameter. Accurate diameter determinations can also be made by observing occultations of Titan by the Moon; however, lunar occultations cannot provide any useful information about Titan's atmosphere.

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