ATMOSPHERIC PROPERTIES OF JUPITER DETERMINED FROM GALILEAN SATELLITE ECLIPSE LIGHT CURVES

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Abstract. Twelve eclipse light curves for the Galilean satellites have been observed at 30 colors. The shape of the curves depend upon Jovian atmospheric properties such as Rayleigh scattering, aerosol distribution, molecular absorption, scale height and cloud top altitude, as well as the satellite diameter. Different zenographic latitudes and longitudes along the sunrise and sunset terminator have been observed. Very long absorption path lengths are obtained compared to normal incidence because of the tangential passage of the Sun's rays. Refractive tails are observed in most cases which allow aerosol distributions to be determined. The other atmospheric properties may also be derived.

1. Introduction

Minor amounts of methane and ammonia in the Jovian atmosphere have been detected spectroscopically along with the molecular hydrogen quadrupole lines. Observation of other species is difficult because of the short absorption path lengths for normal incidence spectroscopy and the small amounts which may be present. As yet, only methane, ammonia and hydrogen have been observed, although there is reason to expect the presences of other gases. The structure of the Jovian atmosphere, however, can be studied in detail by stellar occultation techniques. This method is limited to only the upper most atmospheric layers, however, occultations by bright stars are infrequent.

Eclipses of the satellites, which are frequent, provide another method to study the structure and composition of the Jovian atmosphere. As one of the Galilean satellites pass through the shadow of Jupiter it probes to greater depths in the atmosphere, in some cases, to the cloud deck. Until recently, these observations have been limited to broad band measurements, such as those of Price and Hall (1971). They reported several points on the 'refractive tail' and concluded the existence of an aerosol haze.

Two of the authors (RWS and TFG) started a study of the Galilean satellites in 1970. The observational program with the 200-in. Hale telescope, and the multichannel spectrometer (Oke, 1969) is continuing (Greene *et al.*, 1971; Greene and Shorthill, 1972).

The purpose of this study was to determine the composition and structure of the Jovian atmosphere with the narrow band instrument. Several results of the study will be described. A brief description of satellite eclipse light curves will be given.

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2. Satellite Eclipse Phenomena

The shape of the Jovian satellite eclipse curve is determined by many physical parameters. The detailed theory has been discussed by Price (1970). Some of these physical parameters will be described briefly.

2.1. SATELLITE RADIUS

If the satellite was a point source the light curve would fall off at a very rapid rate determined by the finite solar diameter only. The fall-off becomes less rapid with increasing satellite diameter. After seven to eight magnitudes of darkening the effect of diameter on the shape of the light curve is insignificant, and the shape depends on the other factors.

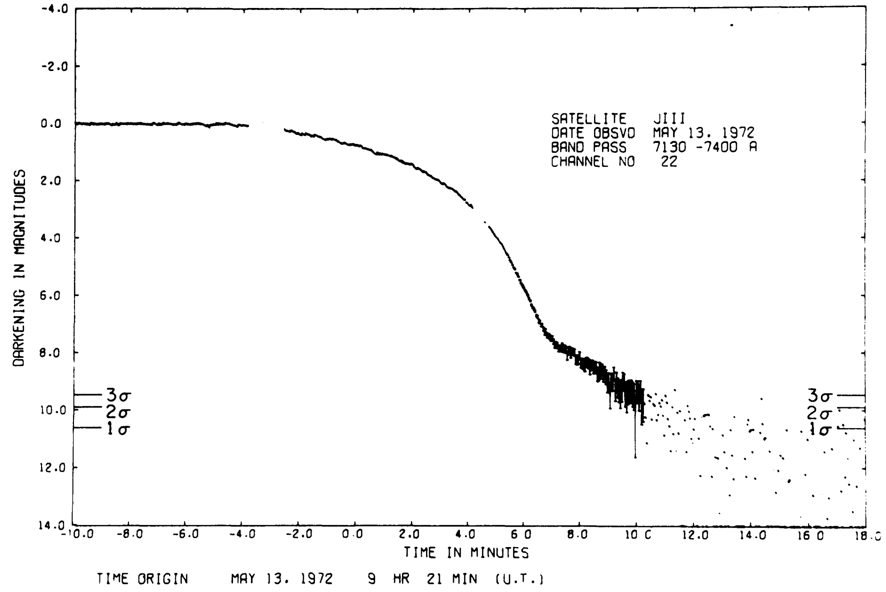

Fig. 1. A typical eclipse light curve for J III, May 13, 1972, in the 7130 to 7400 Å band pass. Data points which are below $m_v = 14$ are plotted at $m_v = 14$. The break in the curve at time +4.0 min results when the telescope aperture is opened to 200 in. from 90 in.

2.2. RAYLEIGH SCATTERING

Sun light is refracted and scattered into the geometric shadow resulting in a 'refractive-tail' extension on the eclipse light curves. The major cause of extinction in the Jovian atmosphere is Rayleigh scattering, whose wavelength dependence is easily observable. For example, at 7300 Å the eclipse light curve exhibits a refractive-tail, as shown in Figure 1, lasting for several minutes. At 11000 Å the refractive-tail is present even longer, while at 5000 Å the light curve falls very rapidly and may show no refractive-tail at all.

2.3. Scale height

If there were no atmosphere, the eclipse light curve would be determined only by the finite size of the Sun. As the scale height increases, the effect of the refraction tends to flatten the light curves. As the scale height increases to large values, the light curves fall-off again more rapidly.

2.4. Extinction due to aerosols

If the ratio of aerosols and gaseous particles is not constant throughout the atmosphere, a wavelength dependency different from that due to Rayleigh scattering will be observed.

2.5. Extinction due to molecular absorption bands

The absorption path is increased greatly compared to normal incidence because the sunlight passes tangentially through the Jovian atmosphere. The presence of an absorbing species may be determined by observing the continuum on either side of the suspected molecular band.

2.6. Cloud top cut-off

At some point ($m_v \geqslant 9$) a ray passing tangentially through the atmosphere will be cut off by the cloud tops. This should be observed simultaneously at all wavelength channels that are above noise.

2.7. Anomalous reappearance brightening

If the albedo of a satellite should increase while it is in totality, then upon reappearance the effect will be detectable as an increase in brightness compared to the pre-eclipse brightness.

2.8. Orbital parameters

The relationships between tilts, rotation, etc., allow different zenographic latitudes and longitudes to be investigated by the eclipse method. For example, J IV probes all latitudes, while J I can probe only a limited range in latitude. The ingress light curves probe the sunset terminator while the egress light curves probe the sunrise terminator on Jupiter. Thus, the measurement of Jovian eclipse light curves provide a method to study the composition and structure of the Jovian atmosphere. Different zones, belts, the red spot, aerosol distribution, meteorological conditions, etc., can be systematically investigated.

3. Observations

Measurements were made at 30 different wavelengths on the four Galilean satellites. A total of 12 satellite eclipses have been observed using the 200-in. Hale telescope.

The wavelength channels are distributed from 3160 to 10680 Å. Below the 5720 Å channel, the band pass varied from 60 to 160 Å, above from 40 to 360 Å depending on the band or continuum being observed. Figure 1 shows an example of an eclipse light curve for Ganymede (J III) in the 7130 to 7400 Å channel (Greene *et al.*, 1974). The refractive-tail is clearly evident out to about ten magnitudes of darkening. At time equals + 13 min (see Figure 1), the ray from the Sun to the satellite has passed through approximately 700 km-atm of gas in the atmosphere of Jupiter.

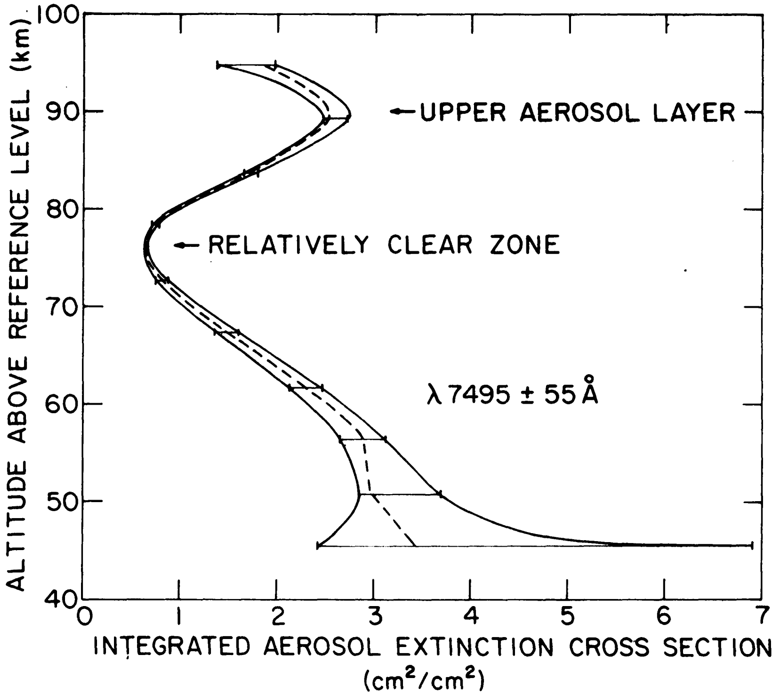

Fig. 2. Aerosol extinction vs altitude above reference level of 10^{20} cc^{-1}. The two solid lines represent the range of the model. The dashed line is the average fit.

An analysis of six continuum wavelength bands 6325, 6850, 7495, 8260, 9260, 10500 Å with an average band width of 145 Å was made to determine the aerosol extinction. Figure 2 shows the results of this preliminary analysis for the 7495 ± 55 Å band. The relatively clear zone is at the 10^{18} cc^{-1} level. Further analysis may allow the determination of the aerosol particle size in the layers.

A comparison of the 6420 ± 20 Å band with several continuum channels furnishes evidence for a tentative identification of the pressure induced dipole $S(0)$ line of the (4, 0) band of H_2. This identification is tentative because contamination from nearby ammonia bands is yet to be determined.

Analysis of other absorption bands is continuing. The absolute timing of both ingress and egress provide new information on the figure of Jupiter. In two eclipses, the region above the Red Spot was probed and analysis of this observation is underway.

There are available almost three hundred light curves (12 eclipses at 30 wavelengths) not all, however, of the same quality. With these data a series of parametric fits are made to theoretical eclipse light curves. In this way the physical parameters of the Jovian atmosphere are being studied. In order to cover more zenographic positions, observations of the Galilean satellite eclipses must be continued and extended to other large aperture telescopes at various geographic longitudes.

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