asteroid belt at 8×10^8 g/year. This result is similar to the observational estimate of 10^9 g/year obtained by Hawkins (*16*) as well as that obtained by Latham *et al.* (*17*) from lunar seismic data, although the flux obtained by the Prairie Network (5×10^{10} g/year) from all sources, including fireballs (*18*), is higher. Including uncertainties in (dM_e/dt), there may be an uncertainty of an order of magnitude in our calculations; however, the resonant extraction mechanism we propose should result in a significant meteorite flux at Earth.

Spectrophotometric study (*19*) of asteroids such as (511) Davida, (814) Tauris, (31) Euphrosyne, (175) Andromache, and (108) Hecuba lying near the boundary of the Kirkwood Gap could permit their identification with known classes of meteorites. Another asteroidal resonance extraction mechanism, utilizing "secular" resonances rather than commensurabilities, has recently been proposed by Williams (*20*) and may be of comparable importance.

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An Atmosphere on Ganymede from Its Occultation of SAO 186800 on 7 June 1972

Abstract. *On 7 June 1972 the third Jovian satellite Ganymede occulted the eighth-magnitude star SAO 186800. Successful photoelectric observations obtained at Lembang, Java (Indonesia), and Kavalur, India, show nonabrupt immersions and emersions, indicating the presence of an atmosphere whose surface pressure is greater than about 10^{-3} millibar. By fitting the two occultation durations as chords to a model disk, the diameter is found to be 5270 (+30, − ~200) kilometers, the major error contribution arising from the uncertain atmospheric thickness below the occultation layer. The derived mean density is 2.0 (− 0.03, + ~0.2) grams per cubic centimeter.*

A search for occultations of stars by planets carried out by Taylor at the Royal Greenwich Observatory indicated that the star SAO 186800 (magnitude 8.0, type K0) would be occulted by Ganymede (JIII) on 7 June 1972 (*1*). The predicted intensity drop was about 5 percent at visible wavelengths.

Since the stellar position was the largest single source of error in the predictions, photographs taken in March 1972 at the observatories at the Cape of Good Hope, South Africa, and Perth, Australia, were analyzed to yield more accurate relative positions of Ganymede and the star. The predictions were accordingly refined. The predicted area of visibility included southern Asia, northern Australia, and eastern Africa. The uncertainty in the relative position of the two bodies was then estimated as 0.3″. The adopted diameter for prediction purposes was 5550 ± 130 km (*2*).

Successful observations of the occultation were made by Hidayat, Carlson, and Johnson at the Bosscha Observatory near Lembang, Java, and by Bhattacharyya at the Kavalur field station of the Kodaikanal Observatory in India. B. A. Smith and S. A. Smith, observing with a portable photometer and 20-cm telescope from Darwin, Australia, were just slightly (50 km; see Fig. 1) south of the actual occultation zone and obtained negative results. The sky was of excellent photometric quality with scintillation noise below average and all equipment functioned properly. An attempt was also made by S. D. Sinvhal at the Uttar Pradesh Observatory in Naini Tal, India, with photoelectric equipment but the fluctuations in sky transparency were too large for any events to be detected.

The photoelectric observations of the event from Lembang (107.6°E, 6.8°S, 1300 m above sea level) were made with the Bosscha twin 60-cm refracting telescopes mounted in the same tube. The sky was clear and of excellent photometric quality. Measurements were obtained with a two-channel photometer, one channel for the red [wavelength (λ) $\approx$ 6000 Å] and the other for the blue ($\lambda \approx$ 4500 Å), with cooled photomultipliers and pulse-counting electronics. Only the data from the red channel, which were of higher quality, are reported here. The accumulated counts (at a sampling rate of 22.25 sec^{-1}) were displayed on a visual readout and recorded with a 16-mm cine camera operated at a framing rate of about 24 sec^{-1}. Also photographed was the display from an accurate quartz oscillator referenced before and after the event to radio station WWV by using an observatory chronometer. The absolute accuracy of the timing is estimated to be ± 1 second; the relative accuracy during the event was ± 0.1 second. Dead-time corrections of approximately 25 percent have been applied to the data. Direct photographs of the event were also taken and have been published elsewhere (*3*). The photoelectric tracing obtained at Lembang is shown in Fig. 2. The immersion and emersion midpoint times are $18^h47^m40.9^s \pm 1.2^s$ and $18^h50^m22.4^s \pm 1.2^s$ in corrected universal time (U.T.C.).

The observations at Kavalur (78.7°E, 12.6°N, 800 m above sea level) were made at the Cassegrain focus of a 1-m telescope with an 8-arc-second aperture. The photometer signal, recorded through a Wratten 89B filter by a cooled RCA 7102 photomultiplier, was amplified by a GR 1230A electrometer and displayed on one of the four traces of a Tektronix 533A oscilloscope with a four trace plug-in module in the chopped display mode and a sweep rate of 2 cm/sec. The other three traces displayed 0.1-second pips from a quartz clock and full-second pips from the same source. The scope was photographed by a modified cine camera with a precision solid-state timer unit. An Accutron clockface was also photographed at the beginning of each frame, providing time calibration. The clock was checked against British Broadcasting Corporation time pips for a few days preceding and following the event, and found to be very consistent. The sky was moderately good with a very thin wisp of cloud present during the occultation, but both the immersion and emersion were detected on both the photographic and potentiometric strip chart records. Figure 3 shows the immersion and emersion light curves, with midpoint times of $18^h49^m21.8^s \pm 0.1^s$ U.T.C. for immersion and $18^h52^m41.8^s \pm 0.1^s$ U.T.C. for emersion.

The outstanding characteristic of the data obtained (Figs. 2 and 3) is that the falloff and subsequent rise in intensity appear to be gradual rather than abrupt. By contrast, the occultation of Beta Scorpii C by Io was observed to be instantaneous to within the time resolution of the instruments (*4*). In the absence of an atmosphere on Ganymede, the intensity change should have been

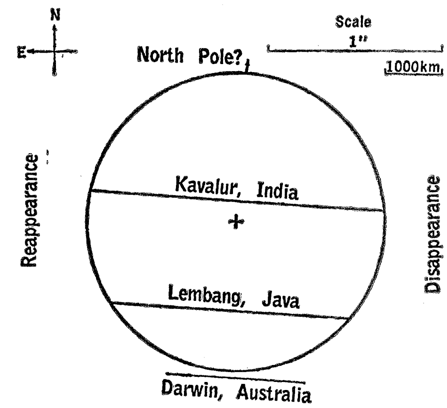
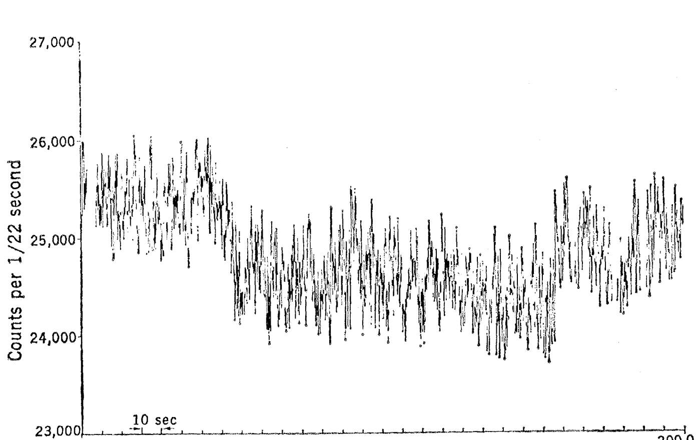


Fig. 1. Apparent path of the star SAO 186800 behind Ganymede as seen from India and Java on 7 June 1972.

more rapid than the ~ 0.05-second integration time of both observations. The presence of an atmosphere would produce a more gradual light curve through refraction.

Reduced Lembang data are available from several minutes before the onset of the event until several minutes after its termination. The tracing of the data in Fig. 2 shows clearly that the occultation was in fact observed. The time of midoccultation was approximately 1 minute from that predicted, well within the accuracy of the prediction. Moreover, photographs taken from Lembang confirm that the events occurred at the times indicated by the photoelectric records. Immersion appears quite gradual, lasting perhaps several seconds. Emersion, while less clear, is also nonabrupt; this interpretation is made a little more difficult by the presence of a noise spike near emersion (Fig. 2). A few additional fluctuations attributable to guiding errors occurred primarily in the postemersion portion of the trace and have been suppressed. The Lembang data also show an irregular modulation of several seconds which is due to scattered light from nearby Jupiter. This did not interfere with identification of the event. In addition there is a gradual decrease in overall intensity during the period of observation due to Ganymede's motion away from Jupiter during the course of the observations. We emphasize that an instantaneous occultation would have been identified by an abrupt intensity change superimposed on the more gradual sources of noise. Such an abrupt change was not observed.

The Kavalur data (Fig. 3) have been plotted on a greatly expanded horizontal scale for two reasons: (i) the total amount of reduced data from Kavalur is much less than from Lembang (approximately 8 seconds on either side of immersion and emersion) and (ii) the resolution of individual data points in the Kavalur data is more important to support our interpretation than is true of the Lembang data on that scale. There are breaks in the Kavalur data due to lack of synchronization between the camera and the oscilloscope, and unfortunately, such breaks occurred near the times of immersion and emersion. The loss of data during emersion is the more unfortunate because of some uncertainty over the validity of the data point designated with a question mark in Fig. 3. The immersion curve provides additional evidence that the falloff is not instantaneous and suggests a falloff time of approximately 0.5 second, although it



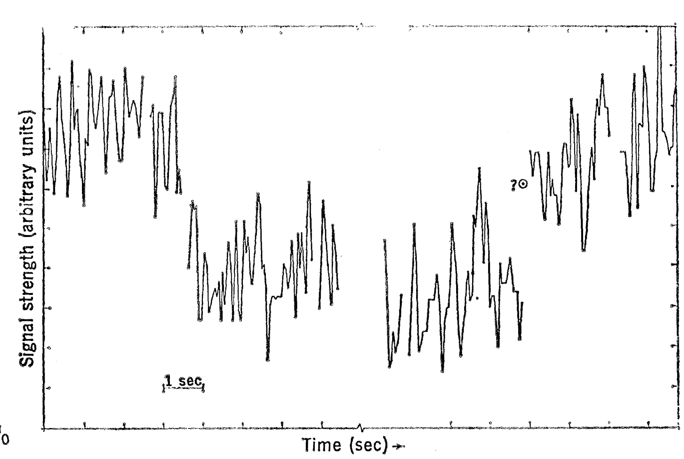


Fig. 2 (left). Photoelectric light curve of the occultation of SAO 186800 by Ganymede from Lembang, Java. Note that the time scale is compressed relative to the Kavalur data (Fig. 3) and that each 10-second interval contains 220 data points. Fig. 3 (right). Photoelectric light curve of the occultation of SAO 186800 by Ganymede from Kavalur, India.

is consistent also with considerably longer falloff times. The emersion curve is suggestive of an intensity rise taking several seconds, but this may be due in part to fluctuations of Jovian scattered light (Jupiter's limb was only 20 arc seconds away) resulting from telescope guiding oscillations which occurred with time scales of the order of several seconds.

The data of Figs. 2 and 3 are not as clean as we might like. They are complicated by scattered light fluctuations, occasional noise spikes, and some data "dropouts." It must be remembered that the intensity drop was only of the order of 5 percent, that the star was itself only eighth magnitude, and that there was some scattered light from Jupiter. Nevertheless, we feel that the data are of sufficient quality to determine the occultation radius and to support the inference that the intensity changes are nonabrupt. Thus it appears that Ganymede does possess at least a modest atmosphere.

If we fit the two sets of observations as chords to a model disk (Fig. 1) we find a discrepancy of about 5 seconds between the absolute times of the two observatories. This discrepancy is too large to be explained entirely by the gradual nature of the events, yet too small to erode our confidence that the occultation was in fact observed at both locations. There is the possibility of an error in the setting of the clock at one observatory or the other. Also difficult to interpret completely is the suggestion that the immersion and emersion recorded from Lembang were more gradual than those from Kavalur. It is clear that deriving a meaningful scale height and composition of Ganymede's atmosphere from the shape of the light curves is impossible.

However, it is possible to set a lower limit to Ganymede's surface pressure and to determine the radius at that level. The data suggest a surface pressure greater than $\sim 10^{-3}$ mbar (attributable to the lack of any noticeable abrupt event in the photoelectric record). Infrared observations suggest an upper limit of less than ~ 1 mbar (*5*). Further analysis of the data may narrow these limits. Spacecraft radio occultations may shed additional light in the near future on the nature of Ganymede's atmosphere.

An analysis was made by using the four observed times (which were all given equal weight) in conjunction with ephemerides of Jupiter and Ganymede. The equations of condition contained three unknowns: corrections to the right ascension, declination, and adopted semidiameter of Ganymede. Assuming a circular cross section, the diameter of Ganymede was found to be 5271 km. The formal standard error of this value was only 1 km, but this is of no significance: whereas the standard error of the times at Lembang is 1.2 seconds, the largest time residual is less than 0.1 second. In view of the standard error of the observed times at Lembang it is more realistic to consider that the standard error of the diameter is of the order of 20 to 30 km.

On the other hand, the presence of an atmosphere on Ganymede makes uncertain the lower limit to the diameter. If the surface pressure were as high as about 1 mbar the occultation layer at a pressure of about 10^{-3} mbar would be located seven scale heights above the solid surface. Assuming a mean molceular weight of 28 (molecular nitrogen) and a temperature of 100°K, the scale height would be about 20 km and the solid surface would lie about 140 km below the occultation layer. The figure would be even greater for constituents of lower molecular weight and for a warm atmosphere. We conclude that the diameter of Ganymede is 5270 ($+ 30$, $- \sim 200$) km, and the mean density 2.03 ($- 0.03$, $+ \sim 0.2$) g/cm^3.

Because of its slow (synchronous) rotation rate (the period of rotation is 7.155 days) the equatorial flattening of Ganymede should be very small. If we make the reasonable assumption that Ganymede is a homogeneous fluid body in hydrostatic equilibrium, the equatorial radius would exceed the polar radius by less than 1 km and the permanent tidal bulge directed toward Jupiter would be only ~ 2 km greater than in an orthogonal direction (*6*). Therefore, the assumption that Ganymede is spherical is well within the accuracy of these observations.

The recognition that observable occultations of stars by the Galilean satellites are relatively frequent and the improvement of the mechanisms of prediction could well result in our having accurate information about satellite atmospheres, diameters, and mean densities by the end of the decade (*7*).

The discovery of an atmosphere on Ganymede together with previous negative results for Io (*4*) suggest that Ganymede should receive first priority for radio occultation or other atmospheric experiments on the Pioneers and other Jupiter spacecraft.

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