weathered deposits were exposed at the surface for a long time before being covered by products of the next eruption. Radiocarbon dating of the youngest weathered deposit in such a profile, as well as of the oldest deposit above it, discloses the approximate length of a dormant interval. The imprecision of the radiocarbon dating method, which amounts to only a few hundred years, is minor relative to the total length of the dormant interval.

Dormant intervals of a few centuries are hard to recognize because weathering profiles developed in such short intervals are weak. The lengths of short intervals are also determined by radiocarbon dates, but the imprecision of the method is then large relative to the length of an interval. However, the radiocarbon method seems adequate to approximate intervals of several hundred years (Fig. 3) where there are many dates and good stratigraphic control.

During the last four millennia there has not been a dormant interval of as much as a thousand years at Mount St. Helens. Within this time, however, there were five or six intervals of more than two to about five centuries before A.D. 1800 during which the volcano seems to have been dormant. In addition, 12 dormant periods of one or two centuries in length have tentatively been identified, and many intervals of a few years or a few decades surely occurred during extended periods of eruptive activity.

A forecast. The repetitive nature of the eruptive activity at Mount St. Helens during the last 4000 years, with dormant intervals typically of a few centuries or less, suggests that the current quiet period will not last a thousand years. Instead, an eruption is likely within the next hundred years, possibly before the end of this century. Because of the variable recent behavior of the volcano, we cannot predict whether the next eruption will be of basalt, andesite, or dacite, and whether it will produce lava flows, pyroclastic flows, tephra, or volcanic domes. But if the eruptive period lasts years or decades, a variety of eruptive events and lithologic types can be anticipated (*12*).

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11 October 1974; revised 10 December 1974

Callisto: Disk Temperature at 3.71-Centimeter Wavelength

Abstract. *We observed the radio emission of Callisto* **with a** *three-element interferometer at the time of the 1973 opposition of Jupiter. Special care was taken to remove the residual, unresolved contribution from Jupiter itself in the antenna side lobes. The resulting disk temperature at a wavelength of 3.71 centimeters, assuming a radius of 2500 ± 75 kilometers for Callisto, was 101° ± 25°K. This temperature is much more consistent with emission from a simple dielectric sphere than the considerably higher temperatures that have been reported for wavelengths of 3.5 and 8.2 millimeters.*

To determine the feasibility of making radio measurements of the Galilean satellites, one can calculate approximately what flux density to expect for thermal emission from a given satellite at a given wavelength. The radii are known from optical measurements, the disk-average temperatures can be estimated from infrared measurements or from equilibrium considerations, and a guess can be made for the radio emissivity. The Galilean satellites turn out to be very weak radio sources but, nevertheless, are well above the detection limit for some existing instruments in the wavelength range from a few millimeters to a few centimeters.

In this case, however, the detection limit is not the only constraint. Another problem is the close proximity of Jupiter, a radio source about three orders of magnitude stronger than the Galilean satellites. This problem has delayed attempts to measure the disk temperatures (T_D) of the Galilean satellites, and it makes Callisto the easiest satellite to measure and Ganymede the next easiest, partly because of their larger sizes but mainly because of their larger distances from Jupiter.

The first published measurement was that of Gorgolewski (*1*). The resulting T_D for Callisto at a wavelength (λ) of 3.5 mm was 276° ± 87°K, assuming a radius of 2500 km. This is about twice the value that was expected, and an attempt to explain the high value was made by Kuz'min and Losovsky (*2*). They assumed that Callisto has a thick ice crust (*3*) that is very transparent to radio waves and has a temperature gradient that increases toward the interior. For their model they argue that in the microwave range one will "see" a brightness temperature of 200° to 220°K independent of the frequency.

Evidence has been reported (*4*) for water ice or frost on Callisto, but for only a small fraction of the surface area. Kuz'min and Losovsky argue that there may be a very thin layer of silicate debris overlying and obscuring the ice. A serious difficulty, however, is the very large penetration depth determined by Kuz'min and Losovsky and required to get a significant brightness temperature enhancement from their model. The ice will be very transparent, to be sure, but a penetration depth of many tens of kilometers, as required, appears to be some orders of magnitude too large according to recent determinations of the opacity of ice. The next published measurement was by Kuz'min and Losovsky (*5*). Their result at $\lambda = 8.2$ mm was $T_D = 234° \pm 100°K$, assuming a radius of 2500 km. They believed that this measurement gave added support to their model.

To shed some light on these matters and to gain experience in difficult detection observations, we measured the T_D of Callisto at $\lambda = 3.71$ cm near

Jupiter opposition in 1973. We have learned that measurements at $\lambda = 2.8$ cm were carried out by Pauliny-Toth *et al.* at about the same time, not only for Callisto but for Ganymede as well (*6*).

Our observations were made at 8085 Mhz with the three-element interferometer at the Owens Valley Radio Observatory. The instrument consisted of three steerable paraboloids, with diameters of 27.4, 27.4, and 39.6 m, positioned such that the antenna separations were 365.8, 700.3, and 1066.1 m, all in the east-west direction. The shortest base line was formed by the two smaller antennas. The period of observation, 24 July to 5 August 1973, was chosen to be centered approximately on the date of Jupiter opposition. Degenerate parametric amplifiers were employed on each antenna, giving a system temperature of about 90°K for each interferometer pair. The IF (intermediate-frequency) center frequency and bandwidth were about 10 Mhz and 5 Mhz, respectively.

The instrumental response consisted of linear polarization of any chosen position angle. The Callisto records, each 20 minutes in duration, were made with the position angle of the electric-vector set alternately at either 343° or 73°, that is, parallel or perpendicular to Jupiter's polar axis. A calibration of amplitude and phase on a nearby standard radio source was taken every 80 minutes. Callisto was observed for three nights near its eastern elongation and for three nights near its western elongation. An additional six nights were devoted to observations at positions relative to Jupiter that duplicated the Callisto observations of other nights, but with Callisto out of the beam.

In the flux density calibration we relied on several primary standard radio sources. These sources and their assumed flux densities (S) (in janskys) (*7*) were as follows: 3C48 (3.4), CTA21 (1.8), 3C138 (2.8), 3C286 (5.5), and CTA 102 (2.9). The flux densities of two sources reasonably close to Jupiter, NRAO530 and P2203-18, were determined relative to the standards (5.1 and 3.4 janskys, respectively). These two sources were then used to calibrate both the flux density and the phase for Callisto.

The success of the observations depended primarily on removing the contribution from Jupiter sufficiently well to obtain a meaningful flux density for Callisto. This was accomplished in a combination of ways. During the observations the antennas were pointed at Callisto, which was about two beam widths away from Jupiter. This in itself led to a strong, albeit inadequate, suppression of the Jupiter contribution. Another desirable suppressing effect was provided by the interferometer. The Jupiter emission was highly resolved by the interferometer, particularly at the longer base lines. The final removal of the Jupiter contribution was accomplished by carrying out a vector subtraction of the off-Callisto measurements from the corresponding on-Callisto measurements.

Table 1. Calculated values of T_D (in degrees Kelvin) as a function of T_v for two values of the dielectric constant ϵ.

ϵ	T_v (°K) 60°	50°	40°	30°	20°
3.0	96°	104°	112°	121°	129°
2.5	99°	107°	115°	123°	132°

The off-Callisto measurements were made on nights when Callisto was unavailable because it was too close to conjunction with Jupiter. For every Callisto record there was a corresponding record, with Callisto out of the beam, that duplicated in every respect possible the Callisto record. Great care was taken to duplicate the offset from Jupiter, the hour angle of the record, the polarization, and the calibration. The vector subtraction of the two-dimensional interferometer response was then carried out record-by-record. Because Jupiter was at opposition, the interferometer visibility of Jupiter versus the hour angle was almost the same from night to night except for possible variations in the central meridian longitudes of Jupiter. It was not possible to duplicate the central meridian longitudes for the off-Callisto measurements because there were too many other constraints.

Confusion from background sources was not negligible for these observations. The root-mean-square confusion level was comparable to the Callisto flux density. To remove the confusion contribution, we relied on the motion of Callisto relative to the background to randomize the phase of the confusion so that it would add incoherently in the final vector sum. The confusion did add to the scatter of the data as a random error, however.

For the purpose of pointing the antennas, we prepared a Callisto ephemeris, using information supplied in *The American Ephemeris and Nautical Almanac* (*8*). It was always correct to within several arc seconds and was completely adequate for antenna pointing. However, it was not adequate for reducing the data. In order to avoid any loss of coherence when combining the interferometer data, the ephemeris must be accurate to a small fraction of a fringe spacing. We are indebted to J. Lieske of the Jet Propulsion Laboratory for providing us with an ephemeris having sufficient accuracy.

All the records were corrected for resolution on the assumption that Callisto is a uniform circular disk with a radius of 2500 km. The largest correction was about 4 percent. The results of all the vector subtractions were then averaged vectorially, with the three base lines weighted appropriately, to produce the final result: $S = 10.85 \pm 2.64$ millijanskys (*7*) at 4.04 A.U. For a radius of 2500 ± 75 km (*9*) this gives an equivalent blackbody T_D of $101° \pm 25$°K. The contribution of the radius and calibration uncertainties to the final uncertainty is almost negligible. The main causes of the final uncertainty, contributing about equally, are the system noise and the scatter due to the Jupiter emission and the background confusion. However, the uncertainty due to system noise is twice as large as if there had not been the need to remove the Jupiter emission. Observing half the time with Callisto out of the beam and the subtraction process each multiplies the noise by $\sqrt{2}$.

Since Callisto has little or no atmosphere, one would expect that the surface temperature, essentially the infrared temperature, would vary primarily as a function of solar zenith angle (θ). We could carry out a detailed calculation of the surface temperature using numerical methods, but our knowledge of the relevant parameters is too poor to make this useful. If we simply equate the solar insolation to the reradiation given by the Stefan-Boltzmann law, we obtain the usual result for the sunlit portion of a slowly rotating sphere:

$$T_s(\theta) = [(1 - A)S_{\odot}/\sigma E_{IR}]^{1/4}R^{-1/2}\cos^{1/4}\theta = T_{ss}\cos^{1/4}\theta \quad (1)$$

where T_s is the surface temperature, T_{ss} is the subsolar surface temperature, A is the Bond albedo, E_{IR} is the infrared emissivity, $S_{\odot}$ is the solar constant, σ is the Stefan-Boltzmann constant, and R is the distance from the sun in astronomical units. We find that $T_{ss} = 173$°K for $A = 0.10$, $E_{IR} = 0.95$, and $R = 5.1$ A.U.

At a radio wavelength where we are "seeing" to some depth below the surface we can estimate the temperature by use of the Piddington and Minnett lunar theory (*10*). A simplifying assumption for what follows that is quite valid for Callisto is that the subsolar and subearth points are the same and lie on Callisto's rotational equator. To apply the theory we need a crude approximation for the surface temperature (and for Eq. 1) of the form:

$$T_s(l,b) = \cos^{1/4}b\ (T_0 + T_v \cos l) \tag{2}$$

where l is the longitude from the subsolar point, b is the latitude, and $(T_0 + T_v) = T_{ss}$ (T_0 is a constant temperature and T_v is the amplitude of the part of the temperature that varies with longitude). The theory essentially solves the heat transfer problem, where Eq. 2 is used as the boundary condition to yield the brightness temperature:

$$T_B(l,b,\lambda) = E(l,b,\lambda) \times \cos^{1/4}b\{T_0 + \left[\frac{T_v}{(1 + 2\delta + 2\delta^2)^{1/2}}\right] \times \cos(l - \psi)\} \tag{3}$$

with

$$\psi = \tan^{-1}[\delta/(1 + \delta)]$$

and

$$\delta = (\omega\rho c/2k)^{1/2}\lambda/2\pi\sqrt{\epsilon}\tan\Delta$$

where $E(l,b,\lambda)$ is the emissivity at wavelength λ, ω is the rotation rate with respect to the sun, ρ is the density, c is the specific heat, k is the thermal conductivity, ϵ is the dielectric constant, and $\tan \Delta$ is the loss tangent.

For the moon δ (ratio of electrical skin depth to thermal skin depth) ≈ 2.4 λ with λ in centimeters (*11*). If we assume that the soil parameters for Callisto are the same as those for the moon, this result can be scaled by $(\omega/\omega_{☾})^{1/2}$ to give $\delta \approx 3.19\ \lambda$ for Callisto. By coincidence, this value of δ is approximately the same value that we would expect for a solid ice surface. The value of T_B from Eq. 3 then becomes at 3.71 cm:

$$T_B(l,b,3.71 \text{ cm}) = E(l,b,3.71 \text{ cm}) \times \cos^{1/4}b[T_0 + (T_v/17.5)\cos(l - 43°)] \tag{4}$$

As expected, the variation of physical temperature with longitude is now greatly attenuated and shows that at our wavelength of 3.71 cm we have essentially reached the isothermal layers of Callisto.

The quantity $E(l,b,\lambda)$ can be determined from ϵ using the Fresnel reflection coefficients, and T_D can be found from:

$$T_D = \int_{\text{disk}} T_B(l,b,3.71 \text{ cm})\ d\Omega/\Omega \tag{5}$$

where Ω is the solid angle of Callisto. With different guesses for T_v we find the values of T_D shown in Table 1. Although the model temperatures tend to be slightly higher than our measured result, the agreement is good considering the uncertainties both in the model and in the measurement. If we simply scale directly from the moon using only the factor $(R/R_{☾})^{-1/2}$, we also find good agreement. The linear polarization to be expected because of the departure of our model from circular symmetry is well below 1 percent and could not have been detected in the observations.

The model is, of course, oversimplified. Not only is there the crude approximation for T_s (Eq. 2), the uncertainty in estimating T_v, and the approximate theory, but we have also not considered the effects of surface roughness. However, we have shown that the measurement is consistent with what would be expected for a dielectric sphere: our measurements do not permit us to distinguish between a lunar-type soil and a solid ice surface. The measurement is in agreement with the observations of Pauliny-Toth *et al.* (*6*) at $\lambda = 2.8$ cm which yield $T_D = 88° \pm 18°$K for Callisto, although their result is in somewhat worse agreement than ours with the model calculations. The results are in considerable disagreement with those of Gorgolewski (*1*) and Kuz'min and Losovsky (*5*), despite the slightly higher temperature to be expected at the shorter wavelengths.

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9 September 1974

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Morphine-Dependent Rats: Blockade of Precipitated Abstinence by Tetrahydrocannabinol

Abstract. *Male rats were implanted subcutaneously with a pellet containing 75 milligrams of morphine base or placebo, and naloxone hydrochloride (4 milligrams per kilogram of body weight) was administered 72 hours later. Treatment with Δ^9-tetrahydrocannabinol (2, 5, or 10 milligrams per kilogram) 1 hour before naloxone administration significantly reduced the intensity of abstinence; the two higher doses blocked the appearance of wet shakes and escapes, diarrhea, and increased defecation. Δ^9-Tetrahydrocannabinol did not induce abstinence itself, and prior treatment with cannabidiol was ineffective in reducing naloxone-precipitated abstinence in animals with morphine pellets. These data suggest that Δ^9-tetrahydrocannabinol may be of value in facilitating narcotic detoxification.*

Many compounds classified as narcotic antagonists possess some properties characteristic of narcotic agents themselves, and are thus termed "partial narcotic (opioid) agonists" (*1*). Many of these pharmacological properties, such as analgesia, hypothermia, and respiratory depression, are also exhibited by Δ^9-*trans*-tetrahydrocannabinol (THC), a major psychoactive constituent of marihuana (*2*). Despite a lack of more definitive evidence relating narcotics and the cannabinoids, we attempted to determine whether THC could act antagonistically to the effects of morphine in rats. We report that a single administration of THC produced a dose-related blockade of