tered were found in the Caroline area overlying Neogene basalt. Thus, the Darwin Rise faces abandonment as a useful working hypothesis. The sequence of layers described above was initially assumed to be time stratigraphic (*9*). The drilling results indicate that the boundary between the "upper transparent layer" and the "opaque layer" is broadly transgressive, ranging from Oligocene south of the Hawaiian Islands to mid-Cretaceous east of the Mariana-Bonin arcs.

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2. The National Science Foundation's oceanic coring program began with the Cuss 1 drilling associated with the Mohole project and was continued on the Blake Plateau. It is now centered on the Deep Sea Drilling Project, directed by the Scripps Institution of Oceanography with the advice of JOIDES. This project consists of a far-flung drilling program by the Global Marine ship *Glomar Challenger*.
3. The *Glomar Challenger* has completed five legs of its drilling cruise in the Atlantic Ocean and five legs in the Pacific. The drilling reported here was accomplished on leg 6, Hawaii to Guam, from 11 June to 5 August 1969. A total of 125 cores with an aggregate length of 684 m were recovered from 17 drill sites.
4. The age of oceanic basement has been estimated to a remarkable degree of accuracy on the basis of magnetic anomaly patterns [W. C. Pitman, III, and J. R. Heirtzler, *Science* **154**, 1164 (1966)]. The linear anomalies observed are presumed to have formed at the axis of accretion.
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29 January 1970

Jupiter: His Limb Darkening and the Magnitude of His Internal Energy Source

Abstract. *The most accurate infrared photometric observations (8 to 14 microns) to date of the average limb darkening of Jupiter have been combined with the most refined deduction of jovian model atmospheres in which flux constancy has been closely maintained in the upper regime of radiative equilibrium and a much more accurate approximation of the 10- and 16-micron vibration-rotation bands of ammonia has been incorporated. The theoretically predicted emergent specific intensity has been multiplied by the spectral response function and folded (mathematically convolved—intersmeared) with the spatial response function of the atmosphere-telescope-photometer combination. The resulting comparison indicates that Jupiter is radiating from three to four times as much power as the planet is receiving from the sun.*

In the next decade it is likely that spacecraft missions will be launched to all of the remaining known planets of the solar system (*1*). Jupiter, the most gigantic member of this group of celestial bodies, has been a source of profound enigmas (*2*). One of the most significant of these has been the suggestion that he may be radiating energy at a rate that is greater than that at which he is receiving energy from the sun. For example, by making bolometric observations of the jovian reflected sunlight, Taylor (*3*) deduced that the jovian effective temperature (that of a blackbody of equivalent bolometric luminosity), if Jupiter's only source of energy is the sun, should be 105°K. He compared this with the brightness temperature at 8 to 14 μ (that of a blackbody of equivalent surface brightness or specific intensity in the same wavelength range) of 128°K and suggested that Jupiter was radiating two to four times as much energy as he was receiving from the sun. Unfortunately, the 8- to 14-μ band pass contains a very small fraction of the jovian thermal spectrum, and, although brightness temperatures at other wavelengths have also been higher than 105°K by varying amounts, the collection of such measurements cannot be synthesized into a bolometric result because of the absence of measurement over significant wavelengths where extraterrestrial radiation is blocked by the earth's atmosphere. Direct bolometric observations made from high-flying aircraft have yielded an effective temperature of 134°K (*4*). However, the absolute calibration of such measurements is difficult and the proper correction for residual absorption in the earth's atmosphere is especially uncertain. The suggestion of the jovian power excess is thus confirmed, although the question of its magnitude invites further discussion.

One approach to the problem of the total luminosity of Jupiter is through the predictions of a model atmosphere for which the true effective temperature is a characteristic parameter. We have approached this problem in terms of a comparison between observed limb darkening in the 8- to 14-μ band pass and the theoretically predicted brightness distribution.

The basic theoretical approach to the determination of the model atmospheres has been described (*5*). In general, it is assumed that the lower regime of the model is convective and that radiative equilibrium prevails in the region above the level at which ammonia condenses. In the models hydrostatic equilibrium is assumed. The source of continuous opacity to thermal radiation lies in the pressure-induced translational and translational-rotational interactions in molecular hydrogen and hydrogen-helium mixtures (*6*). Although the ammonia band absorption is a rather insignificant contributor to the mean opacity (hence to the temperature structure of the atmosphere), it is quite important in the region from 8 to 14 μ and thus cannot be neglected in a determination of the emergent specific intensity from 8 to 14 μ. The primary theoretical contribution of the study reported here has been the incorporation of the ammonia bands at 10 and 16 μ into the model.

We have developed [the details of the new theoretical innovations will be described elsewhere (*7*)], line by line, an empirical, theoretical model of the NH_3 bands at 10 and 16 μ, essentially by fitting the Ladenburg-Reiche theory of the curve of growth to laboratory data and invoking line profiles which are Lorentzian at the core but which vary according to an arbitrary power of frequency displacement in the wings. The latter assumption was crucial and made possible an excellent fit. Considerable variation in pressure and path length appears in the experimental spectroscopic literature, but low resolution requires that one make assumptions regarding half-widths of individual lines. We assumed that the half-widths were equal. The half-width thus emerges in the data-fitting. This assumption, although not strictly correct, is not crucial. Although the different pressure-broadening abilities of He and H_2, as compared to those of NH_3, have been taken into account, any possible distinction in the actual resulting line shape has been neglected. The laboratory data available to date were gathered entirely at room temperature; thus it has been necessary for us to assume that we may adequately take into account the much lower jovian temperature by altering the Boltzmann factors and partition function of the bands, and that the incorporation of assumptions according to the method of Townes and Schawlow (*8*) regarding the theoretical dependence of collisional half-width on temperature will also suffice in this matter. With effective values for pressure, path length, and core and wing temperature, as deduced from a given jovian model atmosphere at a given value of cos θ (the angle of specific intensity with the local vertical), we used the implied transmission for the molecular band model to diminish the emergent specific intensity of the model atmosphere as computed with these bands neglected. The resulting frequency profile from 8 to 14 μ was weighted according to the product of the earth's atmospheric transmission and the spectral response of the photometer used to collect the corresponding observations.

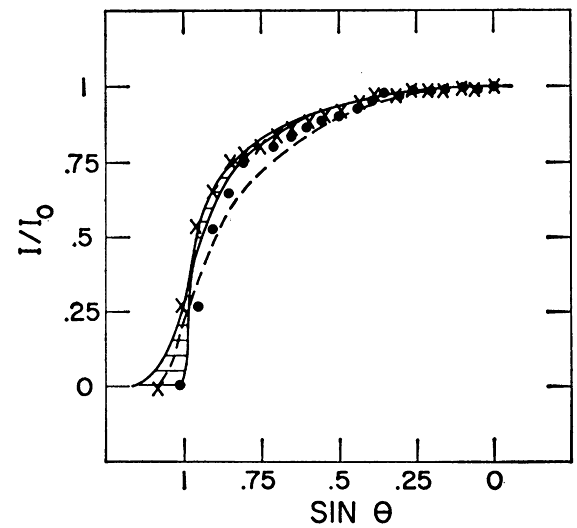

Fig. 1. Theoretical and observational limb-darkening curves of Jupiter between 8 and 14 μ; I/I_0 is the ratio of the specific intensity (surface brightness) at a given value of sin θ to the specific intensity emitted vertically (observed at the center of the jovian disk). The shaded region represents model results for seeing values from 1 to 5, representing seeing tremor due to atmospheric turbulence from a blur of approximately 0.3 to 5 arc sec. The model chosen is characterized by an effective temperature of 150°K and a helium-to-hydrogen ratio of zero. The X's represent observations scaled to this model for a seeing value of 3. The dashed curve represents model parameters identical with those of the shaded region except that the effective temperature is 130°K. Dots represent observations scaled to the dashed curve.

In addition, the resulting theoretical limb darkening was precisely smeared to reproduce the effects of astronomical "seeing" and of a nonzero photometer aperture.

We thus neglected any greenhouse effect due to NH_3, which can be incorporated into the model only with considerable difficulty. Preliminary computations indicate that the neglect is justified, although this conclusion is not entirely unambiguous.

In order to determine the limb darkening of Jupiter we made infrared scans across an approximate jovian diameter. The 200-inch (508-cm) Hale telescope of the Palomar Observatory was used. A total of 41 scans were collected on various dates throughout the 1965 apparition. As equatorial diametric scans, they are estimated to have passed within about 5°, or possibly 10°, of jovodetic arc of the center of the disk (arc-segments along planetary circumferences passing through Jupiter's sub-earth point), and the angle of the scan line with the projected jovian pole varied from about 73° to 77°. The scan direction was actually in right ascension at the rate of +2500 seconds of arc per hour. A mercury-doped germanium photoconductor cooled with liquid hydrogen was used. Aspects of the technique and photometric system have been reported (*9*). The scans were statistically analyzed and synthesized into a mean according to a data reduction scheme which will be presented elsewhere (*7*).

In order that we might compare theoretical predictions with observations, we have normalized the analyzed observational limb-darkening curve to a central value of unity and have calibrated its abscissa in terms of sin θ by requiring the areas under the observational curve and the smeared theoretical curve to be equal.

A comparison which is sufficient to demonstrate the high value of the jovian effective temperature is shown in Fig. 1. The higher effective temperature is favored in spite of the fact that the method of calibrating the observational sin θ axis separately for each fit tends to minimize, if anything, the distinction in goodness of fit between theory and observation for the two cases. By comparison, the change in the helium-to-hydrogen ratio to 1 produces a small effect, which has been computed but is not shown.

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22 December 1969; revised 24 March 1970