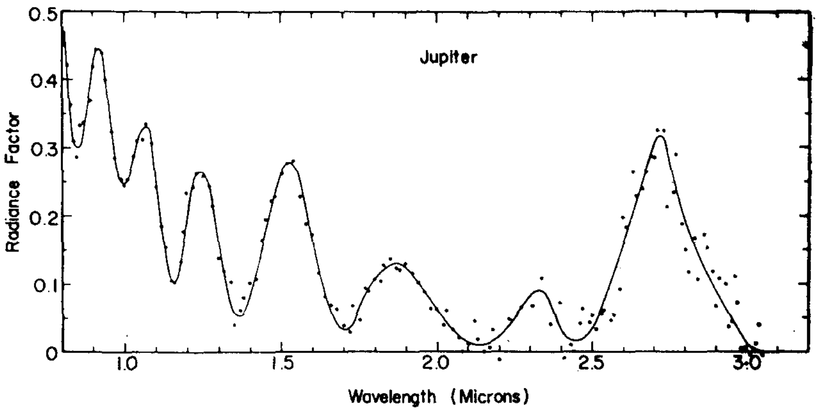

Fig. 4. The radiance factor of Jupiter in the infra-red.

spectrum of Sirius with the predicted spectrum (Woolf, Schwarzschild and Rose, 1965). The only terrestrial feature detected in the spectrum of Sirius was a slight depression at 2·7μ due to atmospheric CO_2. The wavelength calibration was established by scanning a didymium source during the flight.

Fig. 4 shows the radiance factor of Jupiter (the observed brightness of a white diffuse screen at Jupiter's distance which is normal to the Sun's rays). The absolute accuracy is uncertain by at least 20 per cent. The bands at 0·85μ, 0·99μ, 1·16μ, 1·37μ and 1·7μ all appear to be due to CH_4. The fundamental band of NH_3 at 3300 cm^{-1} causes the large absorption at 3·0μ.

The feature of most interest in the spectrum is the deep, broad absorption centered at about 2·25μ. It has two likely causes:

(1) The pressure induced band of H_2 at 2·4μ and

(2) The combination bands of CH_4 at 2·20μ, 2·32μ 2·37μ and 2·42μ.

Laboratory measurements of the H_2 band (Chisholm and Welsh, 1954) show that the H_2 band extends from about 1·8μ to 2·7μ in approximate agreement with the observed feature. Furthermore, of the order of 10 km-atm² of H_2 will produce the observed amount of absorption. Since the scale height in Jupiter's atmosphere is about 20 km, the required partial pressure of H_2 at the effective reflecting level is of the order of 0·7 atmosphere. Such a partial pressure is consistent with recent estimates of the hydrogen abundance on Jupiter.

One can therefore conclude that the pressure induced dipole band of H_2 at 2·4μ is at least partially responsible for the large feature. The contribution of the methane bands to this feature is uncertain because of the lack of appropriate laboratory data.

Project Stratoscope of Princeton University is sponsored by NSF, ONR and NASA.

REFERENCES

Chisholm, D. A., Welsh, H. L. *Can. J. Phys.*, **32**, 291, 1954.
Woolf, N. J., Schwarzschild, M., Rose, W. K. *Astrophys. J.* In press.

8. *Infra-red spectra of Jupiter and Saturn*

W. Sinton

L. Fredrick has a number of spectra of Jupiter and Saturn with a mica-window image intensifying tube between 9800 and 11 200 Å. The dispersion was 46 Å/mm. The observations were made with the Lowell 24-inch Morgan reflector.

Laboratory spectra of methane and ammonia were made for comparison with the planetary spectra. The intensity of the methane bands were roughly matched with a 22-meter path of methane at 5 atmosphere pressure. The ammonia band intensity was matched with a 22-meter path and a 2/3 atmosphere pressure.

On spectra of the disk of Jupiter no lines were found which could not be explained by either methane, ammonia, solar or terrestrial lines. On Saturn only methane, solar and terrestrial lines could be found. A broad weak band was found in the rings of Saturn at 10 800Å.

Spectra of Io were taken when the satellite was 1 second of arc from the limb just before it was occulted by Jupiter. On this night the seeing was very excellent. No lines of methane or ammonia were found, showing that these gases are not present in any extended atmosphere.

9. *The thermal opacity in the major planets*

G. Münch

Radiometric and visual observations indicate the presence of an infra-red opacity in the Jovian atmosphere, so far unidentified. Recent laboratory work suggests the importance of estimating the absorption coefficient of molecular hydrogen arising from the distortion of the molecules during collision and from quadrupolar induction. The rotational and translational transitions of this pressure induced absorption appear to play an important role in the energy balance of the major planets. As a preliminary analysis, a gray model in hydrostatic and radiative equilibrium has been constructed by Lawrence Trafton from the monochromatic absorption coefficients of H_2. A Planck mean was used taking into account only the density dependence of the absorption and an effective temperature of 110°K was adopted. The results of the integrations show that a path-length of 30 km-atm of H_2 has sufficient opacity to produce a substantial greenhouse effect and bring the local temperature to 147°K. The radiative temperature gradient becomes unstable against convection at an optical depth in the thermal spectrum of 2·8, where the temperature is 140°K. On this basis it appears that it is possible to construct a model for Jupiter's atmosphere in hydrostatic equilibrium and with no other source of energy than solar radiation.

10. *Color and molecular absorption over the disks of Jupiter and Saturn*

G. Münch, R. L. Younkin

The distribution of color and molecular absorption over the disks of Jupiter and Saturn has been studied photo-electrically with a scanning spectrometer attached to the 60-inch Mount Wilson telescope between 0·33 and 1·1 microns. The limb darkening observed in the strong CH_4 bands at 0·73 and 0·89 microns shows striking differences from those obtained in the neighboring continuum. At λ 0·88 microns we observe in Jupiter a sharp and narrow polar limb brightening, indicating the existence of a very high level cloud, possibly formed by frozen CH_4. Photographs taken through an interference filter center at 0·73 micron confirm the existence of bright polar caps in Jupiter. Additional observations of the major planets at large dispersion are being done photo-electrically with the 100-inch coudé scanner by G. Münch. It has been found that the various bands of NH_3 and CH_4 in Jupiter do not show the same variation in intensity over the disk or toward the limb. It appears that all lines arise by diffuse reflection and that the pressure dependence of the ratio between continuous scattering and band or line absorption coefficients is not the same for all bands. The possibility of studying the variation of the pressure with height through observations of bands or lines of different intensity is thus suggested. A special search for NH_3 features in Saturn has lead to negative results and earlier reports on the presence of NH_3 in Saturn must be considered resulting from misidentification of CH_4 lines in the 0·79 micron region with NH_3 lines.

11. *On radiative transfer in the atmosphere of Jupiter*

C. Sagan

This work has been performed jointly with Dr Andrew T. Young, of Harvard College Observatory, and Dr Philip L. Hanst, of the AVCO Corporation, Wilmington, Massachusetts. Spectra have been taken in a long-path multiple-traversal cell of the quantities of methane and ammonia deduced for the Jovian atmosphere from near infra-red spectra. The laboratory spectra were taken at a variety of total pressures and NH_3 and CH_4 mixing ratios. Since the opacity of ammonia in the 8–13μ region is very high, the temperatures deduced by observations of Jupiter through the 8–13μ interval must apply to a region in the Jovian atmosphere far above the visible clouds. The invisibility of the Great Red Spot in the bolometric observations of Murray, Wildey, and Westphal confirms this interpretation. If the atmosphere above the clouds is in convective equilibrium, the temperature at the cloudtops may be much larger than that deduced from observations at 8–13μ. The infra-red integrated opacities of methane and ammonia, together with the opacity due to quadrupole transitions in hydrogen, computed by Trafton, are very high. Even if the atmosphere above the clouds is in radiative equilibrium, the temperature at the cloudtops must be greater than that deduced in the past. If the atmosphere above the clouds is in convective equilibrium, the temperature at the cloudtops will be so high that their identification as ammonia cirrus must be seriously questioned. Lower vapor pressure materials must then be invoked. On cosmic abundance grounds, the most likely of these is water.

12. *On the temperature and radiative balance of Jupiter's atmosphere*

L. D. Kaplan

Öpik's (1) argument for an internal heat source for Jupiter depends mainly on the opacity from 8 to 14μ being as high as or higher than elsewhere in the spectrum, as this is the spectral region for which brightness temperatures of about 130°K have been obtained. This is, in fact, probably the most transparent part of the spectrum of the Jovian atmosphere. The high opacity observed for laboratory NH_3 out to 14μ is due to the population, at room temperature, of many states with high energy levels. However, of the hundreds of lines between 12·35μ and 14μ or higher, only 19 have lower-state energies corresponding to wave-numbers less than 900 cm^{-1}, and none less than about 600 cm^{-1}. The intensities of these lines would be reduced, at Jovian temperatures, by an order of magnitude, and all the others by two orders of magnitude or more. Below 12·35μ, there are many lines of small lower-state energies, but they tend to clump and provide high opacity over only about one-fourth of the central portion of the band. Applying the above temperature corrections to spectra shown in the previous paper by Sagan, it is seen that the absorption, by 7 m-atm. of NH_3 in the Jovian atmosphere, would indeed be small at wavelengths greater than 12·35μ. Since the blackbody radiation at the low temperatures is heavily weighted toward much higher wavelengths, there appears to be no problem with the heat balance if the atmosphere is opaque at longer wavelengths, as Münch has shown in the previous paper to be the likely result of pressure-induced H_2 absorption.

The wings of the induced dipole lines of H_2 extend below 14μ, and the amount of cloud radiation that is allowed to escape to space depends very strongly on the pressure of the cloud top. If the cloud-top pressure is less than three atmospheres, as seems likely both from the CH_4 line-width measurements by Spinrad and Trafton (2) and from H_2 quadrupole absorption measurements together with estimates of mean molecular weight from occultation measurements, the opacity of the Jovian atmosphere is less than one-half from 9 to 13μ. The cloud-top temperature, as derived from the radiometric measurements, would then be between 140°K

https://doi.org/10.1017/S0251107X00018940 Published online by Cambridge University Press

and 150°K. The small atmospheric opacity is supported by the absence of appreciable limb darkening in the measurements of Murray, Wildey and Westphal (3). (*Münch* indicated in discussion that the amount of limb-darkening at large air-masses is still questionable).

REFERENCES

1. Öpik, E. J. *Icarus*, **1**, 200, 1962.
2. Spinrad, H., Trafton, L. M. *Icarus*, **2**, 19, 1963.
3. Murray, B. C., Wildey, R. L., Westphal, J. A. *Astrophys. J.*, **139**, 986, 1964.

13. *A search for Jovian H-alpha auroral activity*

(Abstract of remarks from *Harlan J. Smith*)

Radio observations, particularly at decametric wavelengths, have shown the existence of strong Jovian radiation belts. Dumping of such particles into the Jovian atmosphere must occur from time to time, if not continuously, presumably producing a Jovian analogue to terrestrial auroras; optical detection of such auroras would permit direct location of Jupiter's magnetic poles.

Search for Jovian auroral activity was undertaken at Yale originally in the H-alpha line among other reasons because the Balmer lines are relatively conspicuous in many terrestrial auroras and because hydrogen is presumably an abundant constituent of Jupiter's atmosphere. A photo-electric comparison spectrophotometer largely designed and constructed by James Rodman (1) was used with the Yale Observatory 20-inch reflector to compare 15 Å centered on H-alpha with a pair of flanking 100 Å comparison bands having edges separated 40 Å from the edges of the H-alpha band. Separate EMI 9558 photomultipliers simultaneously registered the H-alpha and the combined comparison beams, reading into pulse-counting electronics, normally with 2-minute integration times.

Observations were made by setting the edge of a 6 second square slit barely onto the limb of Jupiter at a well-defined position angle on the apparent disk, with subsequent readings advancing by 22°·5 around the limb. In this way the maximum light path through Jupiter's atmosphere was continually sampled over the complete range of latitudes and, with the rotation of Jupiter, over all longitudes. Calibrated reduced ratios of H-alpha intensity to the adjacent continuum were mapped by computer onto a Jovian coordinate system.

More than 3000 observations over the period August–December 1962 (Smith, **2**, **3**) gave H-alpha intensity maps showing no significant average systematic enhancement of H-alpha as great as ·003 over any latitude belt or any small circle that might reasonably be interpreted as an auroral ring surrounding a magnetic pole. That is, this program detected no continuous auroral enhancement of the H-alpha light reflected from the Jovian atmosphere as great as an average of about 3 kilorayleighs.

Factors which may contribute to this failure to detect Jovian auroras to this reasonably high level of sensitivity include the low state of solar activity in late 1962, the possibility that auroras may physically be a night (back-side) phenomenon, and (as suggested by Spitzer) the hydrogen present in Jupiter's atmosphere and ionosphere may be almost entirely molecular.

REFERENCES

1. Rodman, J. P. *App. Opt.*, **2**, 165, 1963.
2. Smith, Harlan J., Rodman, J. P., Sloan, Wm. A. *Astr. J.*, **68**, 79 (abstr.), 1963.
3. Smith, Harlan, J. *Proceedings NASA Conference on Jupiter*. In press, 1964.