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V6097 Final Report

SPECTROSCOPIC OBSERVATIONS OF THE PLANETS

Contract No. NASW-1863

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Project V6097 Final Report

SPECTROSCOPIC OBSERVATIONS OF THE PLANETS

by

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for

Lunar and Planetary Programs
Office of Space Science and Applications
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Contract No. NASW-1863

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V6097 Final Report

SPECTROSCOPIC OBSERVATIONS OF THE PLANETS

This is the final report on Contract No. NASW-1863 entitled "Spectroscopic Observations of the Planets." The contract period extended from February 23, 1969 through November 23, 1969. This report has been delayed owing to the relocation of the principal investigator for a six month leave of absence from the IIT Research Institute to serve as a visiting associate professor at the California Institute of Technology.

1. WORK PERFORMED

The research carried out under the above-referenced contrast consisted of a continuation of the program of ground-based spectroscopic observations of the planets supported by NASA in previous years. During the period under review, new information was obtained about the atmospheres of Jupiter, Venus, and Mars.

1.1 Observations

Since one of the prime goals of the present program was the determination of a better value for the abundance of water vapor in the atmosphere of Mars, an observing run was scheduled at Kitt Peak in early February, before the initiation of the contract, to obtain some preliminary data and to test the ability of the higher spectral resolution presently available to cope with this problem. Instrumental difficulties prevented the acquisition of first class data, but the results obtained were extremely promising, indicating that photographic techniques could provide valuable new data. An eight-night run at the

McDonald Observatory at the end of February and the beginning of March was very successful; high quality spectrograms of Mars were obtained which clearly showed the weak water vapor lines.

New spectra of Jupiter and Venus were also obtained at this time, and these planets were studied again during an eight-night run from June 20-27. The technique of photographing the planets through interference filters centered on strong absorption bands was continued with considerable success, permitting some new conclusions to be drawn about the vertical structure of the clouds of Jupiter.

1.2 Interpretations and Results

1.2.1 Venus

Another unsuccessful attempt to detect emission from the light side of the planet was made in February. The region chosen was 1.08μ where a strong OH band occurs in the terrestrial night sky. The negative result is consistent with the work of other investigators. However, it is felt that the sensitivity of the method can be improved considerably and additional efforts should be made to search for this phenomenon.

The 8200 Å region was observed repeatedly to test for evidence of planetary water vapor absorptions. No planetary lines were found, and neither was a suspected solar absorption reported previously (Owen 1967). It now appears that this interpretation of published reports of water vapor detection in this region of the spectrum is incorrect and these observations must have been faulty in some other respect.

A new carbon dioxide band was discovered at 7105 Å. It has been given the assignment $5\nu_3 + 2\nu_1$ and is the second member of the triad including $5\nu_3 + 2\nu_2 + \nu_1$ found by Spinrad (1962) in the spectrum of Venus at 7159 Å, and previously observed in the laboratory by Herzberg and Herzberg (1953) at very long effective path lengths. It is not yet clear whether these two bands indicate a greater depth of penetration into the planet's atmosphere than the stronger bands at longer wavelengths. The half-widths and temperatures derived from the rotational lines gives no evidence that this is the case, since they correspond to pressures $\leq$ 0.5 atm and temperatures near 240°K. Additional observations at different phase angles and new laboratory work at the low pressures and long path lengths are both essential for a resolution of this question.

1.2.2 Mars

The spectrograms obtained at the McDonald Observatory in February and March were analyzed to obtain the Martian atmospheric water vapor abundance. Nine lines of particular prominence were measured; three of them had laboratory f-values determined at the time of publication of the results. The value for the precipitable water abundance obtained in this way was 35 $\pm$ 15μ. Subsequent additional f-values and new lower state identifications established by B. Farmer at JPL suggest that this number should be revised to 30 $\pm$ 15μ precipitable water.

This is a much larger amount of water than has been suggested for the Martian atmosphere in the past; an average value of 15μ is usually cited. The increase may in part be the result of increased instrumental resolution; an effect that was found to play a significant role in the CO_2 abundance determinations. However, part of it is undoubtedly real and reflects a greater abundance of water in the atmosphere at the time of observation.

This difference is consistent with the difference in the atmospheric temperature gradient reported by Mariner 4 in 1965 versus those established by Mariner 6 and 7 this year. The earlier result indicated an isothermal gradient at 200°K, whereas this year lapse rates of various gradients approaching adiabaticity were reported. A 200° isothermal lower atmosphere would lead to saturation of 30μ of precipitable water, and this is not observed.

Observing time had been scheduled at the University of Hawaii to record the Martian spectrum at the opposite Doppler shift in November, but the telescope was not completed in time for this work.

1.2.3 Jupiter

A number of investigations of this planet were undertaken during the duration of the present contract, and some of these are still in progress, requiring additional observations or laboratory work before they can be brought to fruition. Among these are a search for the 5500 Å ammonia band, a new upper limit on D/H, variations in the cloud top heights, limb darkening in the $3\nu_3$ methane band, and a new upper limit on the methane abundance in possible atmospheres surrounding the Galilean satellites. We shall review these topics briefly below.

The ammonia band at 5500 Å has been well observed in the laboratory by Giver et al. (1969). The strongest line occurs at 5506.4 Å. We have searched for this line at positive and negative Doppler shifts, but have been unable to make an unequivocal identification so far. A weak feature does occur in this position, but additional spectrograms are required to be certain of it. The significance of the observation lies in its application to the problem of the wavelength dependence of the transfer of radiation in the Jovian atmosphere.

The value of D/H in the atmosphere of Jupiter remains poorly known. We have renewed the attack on this question by means of high resolution spectrograms of the 9500 Å region where the 3-0 band of HD occurs. The sensitivity of the new plates obtained by D. L. Benfield (see Section 2 below) and the writer is such that lines as small as 14 mÅ could be detected if present. The HD lines were not found, indicating that a very low limit can be set on the abundance of this gas, once suitable laboratory calibrations are available. The latter requirement is presently under discussion with Dr. K. N. Rao of Ohio State. Assistance also has been offered by Drs. Herzberg and R. A. Durie, who have carried out the only published work on this problem.

The vertical variation in the Jovian cloud structure became evident on photographs of the planet obtained with an interference filter centered on a strong methane band. Using a low resolution spectrogram and a simple Beer's law relation for the dependence of intensity on absorption, we found that the Great Red Spot exhibited an effective reflecting layer 18 km above the region from which 8900 Å radiation is returned elsewhere on the planet. The North Equatorial Belt was also elevated by approximately 12 km (Owen and Mason 1969). This is the first time such an analysis has been attempted and additional refinements in data acquisition and analysis are in order.

The $3\nu_3$ band of methane was observed at the center and limb of the planet to look for possible temperature variations. With the assistance of an analysis carried out by Dr. J. Margolis of JPL, it was established that the limb temperature was 30-40° cooler than the center of the disk. Again, this was a first attempt, and further improvements in the data are expected (see Section 2 below).

Satellites Io and Ganymede were observed at 8 Å/mm with the Carnegie infrared image tube in the region of the very strong 8900 Å methane band. It is now possible to look for individual strong lines of methane to set a very sensitive limit on the abundance of this gas. Suitable laboratory spectra will be obtained at low temperature by Mr. H. P. Mason at IITRI in the next few months.

In addition to these projects, which are still very much in progress, two studies were brought to the best degree of completion that is likely to be achievable in the immediate future. The first of these was a re-evaluation of the helium abundance based on 1.25 Å/mm spectrograms obtained at the McDonald Observatory. After correcting the observed half-widths of weak methane lines for instrumental broadening and using the most recent values for the abundance of hydrogen and hydrogen-methane broadening coefficients, we found H/He $\geq$ 9 (Owen and Mason 1969). Further progress with this technique will require improved spectral resolution, which is not immediately available.

The second project was a new determination of the atmospheric ammonia abundance. This was carried out by Mr. H. P. Mason (see Section 2 below), who first developed laboratory curves of growth for the ammonia bands at 6450 Å and 1.08μ. Using these data, he was able to interpret the equivalent widths of individual lines in these bands as recorded in the Jovian spectrum by the writer to obtain an abundance for the Jovian ammonia. The result was 12 $\pm$ 3 m atm, slightly higher than commonly accepted values that range from 7-10 m atm (Mason 1970). Mason also found evidence for cooler temperatures at the limb of the planet. Previous abundance determinations were not done at high resolution or with the help of curves of growth. However, the new value shares with the earlier results the uncertainty steeming from our present inability to perform a proper temperature analysis of the ammonia bands owing to the lack of suitable rotational quantum number assignments.

2. PARTICIPATION BY STUDENTS

Mr. David L. Benfield of the astronomy department of the University of Texas spent three months at the IIT Research Institute in the summer of 1969 working on the HD problem. He was able to reduce the spectrograms taken by himself and the writer and to evaluate the laboratory data presently available. This work led to the identification of a requirement for new lab data and additional observations timed carefully to take advantage of the planet's large Doppler shift. This project should develop into part of a Ph.D. thesis for Benfield.

Mr. H. P. Mason of the physics department of the University of Illinois in Chicago continued to participate in the program on a full-time basis. The ammonia abundance determination described above formed the major part of a thesis for which Mason was awarded an M.S. in physics in June 1969. He has been promoted to Associate Physicist at IITRI and continues to participate in the planetary research program while working for a Ph.D. at the University of Illinois.

The need for an extensive series of observations of the $3\nu_3$ methane band on Jupiter in order to investigate temperature and abundance variations provides a suitable topic for a doctoral thesis. Mr. Jay Bergstralh of the University of Texas astronomy department has accepted this challenge and will be working on this problem in collaboration with the writer and Drs. J. Margolis and K. Fox.

3. COOPERATIVE INVESTIGATIONS

In response to a request by the writer, Dr. K. N. Rao of the Ohio State University has kindly consented to undertake the investigation of the $C^{13}H_4$ spectrum. Dr. Kenneth Fox of the University of Tennessee will also be involved in this project to aid in the analysis of the laboratory data. The aim is to establish the wavelengths and intensities of enough lines to permit a search for $C^{13}H_4$ in the spectrum of Jupiter and thus a determination of the value of C^{12}/C^{13} in the Jovian atmosphere. At this writing, preparations for the laboratory investigation are well underway and preliminary data are expected to be available within the next two months.

Once this project has been completed, Dr. Rao has expressed an interest in attacking the HD problem also.

4. PUBLICATIONS AND ORAL PRESENTATIONS

"Chemical Abundances in Planetary Atmospheres," by T. Owen, seminar at the Division of Geological Sciences, the California Institute of Technology, March 31, 1969.

"Wavelength Dependence of Polarization XIV. The Atmosphere of Jupiter," (with T. Gehrels and B. M. Herman), Astron. J., 74, 190 (1969).

"Mysteries of the Solar System," review of a book by R. A. Lyttleton, Sky and Telescope, 37, 309 (1969).

"Mars: Water Vapor in its Atmosphere," (with H. P. Mason), Science, 165, 893 (1969).

"The Spectra of Jupiter and Saturn in the Photographic Infrared," Icarus, 10, 355 (1969).

"New Studies of Jupiter's Atmosphere," (with H. P. Mason), J. Atmos. Sci., 26, 870 (1969).

Papers in Press

"Spectroscopic Studies of the Atmospheres of Mars and Venus," (with H. P. Mason), Proceedings of the Symposium on the Physics of the Moon and Planets, Kiev, U.S.S.R., Oct. 15-22, 1968.

"Jupiter and the Outer Planets," Earth and Extraterrestrial Sciences, 1969.

"Cosmology: Planetary Atmospheres," McGraw-Hill Encyclopedia of Science and Technology Yearbook, 1969.

"The Atmosphere of Jupiter," Science, 1970.

"The Exploration of the Outer Solar System," (with D. L. Roberts), Bull. At. Sci., 1970.

"Physics of the Outer Planets," solicited by EST Mondadori for the 1970 Yearbook of Science and Technology.

5. EXPENDITURES

With the completion of the contract, the allocated funds have been exhausted.

Respectfully submitted,
IIT Research Institute

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APPROVED:

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