

instrument parameters, environmental data, etc.). All of this will be recorded automatically; the observer will be prompted to add comments. The data will be written to the archive medium automatically and almost immediately. Several techniques are being considered. One possibility is to use VHS magnetic tape (2.5 Gbyte/tape) at the summit. Alternatively, if a high-speed data link becomes available soon, we could transfer the data to Waimea and record it there either on VHS or perhaps optical disk. Once or twice per semester, the archive tapes (optical disks) will be sent to the Canadian Astronomy Data Centre. At CADC, the tapes will be scanned and the FITS headers checked for completeness and consistency. After any necessary modifications, the header information will be incorporated into the CFHT Catalog. The corresponding data will be copied into the CFHT Archive. At the end of each semester, the portion of the Catalog and Archive which is in the public domain will be expanded to include the data for which the proprietary period has just expired. Access to the Catalog will be primarily by remote log-in with requests for data being transmitted in the same way. It is possible that small data sets can be returned electronically but most request will be handled by mail. CADC's support of the CFHT Archive will be an extension of its primary role, as an archive centre for space data (IUE, HST, AXAF, etc.). The necessary procedures and user interface are already

being developed and tested using existing space data. If there are other institutions within the CFHT community which are capable of supporting the Archive and willing to do so, then the data can be made available to them as well.

While the basic policy on public access applies to *all* data, the extent and timing of its implementation will be determined by practical considerations. This is the second principle which will guide us. The current plan is to implement the program only for data obtained with the second-generation data acquisition system (the HP 9000). In this way we can ensure a high degree of uniformity and completeness, which is essential if the archive is to be useful. Barring unforeseen difficulties, we should be able to start archiving all data obtained with CFHT's CCD's (imaging plus spectrographs, MOS/PUMA, Herzberg, UV Prime, and coudé) in first semester 1989. Insofar as is practicable we will also include visitor instruments which use CFHT's CCD's. The other CFHT instruments (Reticon, FTS, Fabry Péro) will follow later. By first semester 1990, it is expected that all digital data obtained with commissioned CFHT instruments will be part of the archive program.

Comments from the CFHT user community on the archive program should be addressed to the Director and are most welcome.

R. McLaren

The Abundance of Deuterium in the Solar System

Deuterium is destroyed in stars. The D/H ratio in the interstellar medium has therefore decreased since the origin of the Universe. Measurements of this ratio in the solar system are interesting as they can, in principle, provide a lower limit to the primordial abundance of deuterium. This is probably true in the case of the giant planets which have little evolved since their formation. In the case of the terrestrial planets which have lost their primordial atmosphere, measurements of the deuterium abundances have another interest: they can provide information on the evolution of the planets themselves.

There are several ways to measure the D/H ratio in a planet. Possible approaches are direct in-situ mass-spectrometer measurements or the study of D emission lines in the ultraviolet made from Earth-orbit satellites or from a spacecraft. The D/H ratio can also be obtained spectroscopically from the intensity of lines of HD compared with H_2 ($D/H = \frac{1}{2} \times [HD]/[H_2]$), and, more indirectly, from absorptions of other deuterated species such as deuterated methane, ammonia or water (with methane, for example: $D/H = \frac{1}{4} f \times [CH_3D]/[CH_4]$, where f , the fractionation factor, is always higher than 1 and depends on the temperature at which methane equilibrates with the surrounding atmosphere).

However, measurements of the abundance of deuterium in the solar system have not been easy to obtain. In-situ measurements have been made for Venus using two different experiments on-board the Pioneer Venus orbiter and probe. Both measurements appear consistent with a D/H ratio 100 times higher than on Earth, but it would be very important to get an independent confirmation of such a high value. Although several spacecraft have visited Mars, deuterium was never detected. Concerning the giant planets, spectroscopic measurements have been made from the

Earth and with the Voyager spacecraft for Jupiter and Saturn. The D/H ratio was measured in the atmospheric hydrogen and in methane. The only information on the deuterium abundance on Uranus and Neptune came from measurements of the intensities of lines of HD in the visible. However, these lines are badly blended with lines of methane, which prevents one from obtaining good estimates of the abundance of deuterated hydrogen.

A few years ago, we started an observing program dedicated to measurements of the abundance of deuterium in planets in which this isotope had never been detected, or for which the uncertainties in the existing measurements were still too large.

We had detected in the laboratory, near $1.6\mu m$, a band of CH_3D which had never been seen before, and made an extensive study of this band, using high resolution FTS in various laboratories (Meudon, Kitt Peak), because this band might be of interest for the study of deuterium in the coldest planets. We started an observing program with this goal in mind, first at Kitt Peak, with the FTS at the 4-m telescope, and then at CFH as soon as the Cassegrain FTS became operational. At Kitt Peak we detected CH_3D in Uranus and Titan, and, at CFH, CH_3D in Neptune.

1. Venus and Mars

Our search for deuterated species in the terrestrial planets was made at CFH at longer wavelength. We looked for DCI on Venus, HCl being present in the venusian atmosphere, and for deuterated water (HDO) on Mars. These minor constituents can be more easily detected in the regions of the strongest bands. The fundamental bands are located in the thermal infrared. The 1-0 vibration-rotation

band of DCI is centered at $4.8 \mu\text{m}$; the ν_1 band of HDO at $3.7 \mu\text{m}$. The highest possible resolution is required because the lines are narrow, particularly on Mars where the pressure is of a few millibars. The access to a spectral range covering the whole band is another requirement. All the lines will not be usable because of blending with telluric, solar or other planetary lines. A large spectral coverage gives the best chance to detect unblended lines and improve the abundance measurements. Hence, the detection of deuterated molecules on the terrestrial planet could be feasible only if we were able to perform high resolution on a large spectral range, in a region where the thermal background radiation is high.

The CFH-FTS was specifically designed to offer all these capabilities. To be able to achieve high resolution above $2.5 \mu\text{m}$, where the thermal background received by the detectors becomes the main source of noise, this level has to be drastically reduced. For this purpose the FTS works at the infrared Cassegrain focus to optimize the optical efficiency and minimize the overall emissivity from the telescope. The instrument remains cold, at the outside temperature. With two entrances simultaneously matched on the sky, most of the background level is automatically subtracted from the spectrum. A technique of beamswitching provides the cancellation of the residual unbalance. A liquid-nitrogen cooled infrared filter was used in front of the detectors to limit the spectral bandpass ($\sim 200 \text{cm}^{-1}$), exactly matched to the molecular band under study.

The dryness of the site was another important requirement, in particular for the detection of deuterated water on Mars, which is also present in the Earth atmosphere. Observing on Mauna Kea provided the best chance to get dry conditions. In January, 1987, we were able to detect numerous lines of HDO in spectra of Mars, near $3.67 \mu\text{m}$, at a resolution of 90,000 (detection already reported in the CFH Information Bulletin No. 17; paper in press in Science). Another part of the project was the need of an almost simultaneous remeasurement of the H_2O abundance of Mars to deduce a meaningful D/H ratio, since the Martian water vapor has seasonal variations. Such lines were searched for in another spectral range, at $1.1 \mu\text{m}$, on the edge of a telluric water vapor band. This detection was actually more difficult and the deduced abundance less reliable than expected because of the presence of many faint solar lines which have never been analyzed, and could affect the few usable H_2O lines.

In the case of the search for DCI on Venus, the observation by itself was successful but the analysis revealed that the existing models are not able to correctly reconstruct the observed spectrum at $4.8 \mu\text{m}$, a region in which no high resolution spectra had ever been recorded. More CO_2 lines of different isotopic species which are not known or imperfectly measured in the laboratory have to be introduced. Further analysis had to be stopped for this reason. We are now looking for another way of measuring deuterium on Venus. Our plan for the immediate future is to record spectra of Venus near $3.7 \mu\text{m}$ to try to detect the ν_1 band of HDO. The detection will be more difficult to secure than in the case of Mars, because of the extremely small amount of water vapor above the thick clouds of Venus.

2. Neptune

The requirements for the Neptune observations were different. Neptune is intrinsically faint in the infrared. The planet is almost undetectable at $5 \mu\text{m}$. Consequently, the only hope to estimate the D/H ratio on the farthest giant planet was to look for the $1.6 \mu\text{m}$ band of CH_3D . The magnitude of Neptune is about 10.3 in the H band. There was no hope either to obtain a high resolution spectrum. However, this band presents branches with multiples which, even if not fully resolved, give detectable absorptions. A resolution of the order of 2000, assuming a D/H ratio similar to the value obtained on Uranus (de Bergh et al 1986), was considered sufficient to provide a reliable detection in a reasonable observing time. The full coverage of the band was another requirement. Again, the FTS was the most suitable instrument for this program, even at this more modest resolving power, by offering in a single observation the covering of the whole H band.

In order to improve the sensitivity of the instrument a new mode of data recording has been developed. In the current mode the infrared signal is modulated to a frequency chosen to be above the cut-off frequency of the atmospheric scintillation. The response of the detectors with their high value feedback resistor decreases above 100 Hz. On faint objects the scintillation noise, which is proportional to the intensity of the source, becomes negligible. Therefore, a low frequency (20 Hz) is usable, which provided conditions where the detectors are Johnson-noise limited. They have to be used by carefully pumping on liquid nitrogen. This mode of recording at low frequency of modulation was tested for the first time with the Neptune observations. In addition, the capability of recording symmetrical interferograms was introduced to optimize the efficiency of the observations. We were able to obtain a signal-to-noise ratio of 53 over 11 hours and 15 minutes of effective integration at a resolution of 1600 on the whole H band. Such a spectrum of Neptune had never been obtained before. Uranus was also observed at the same resolution for comparison (figure 1). Signatures due to CH_3D were detected and the D/H ratio on Neptune deduced for the first time with some confidence.

3. Scientific results

The consequences of our measurements of deuterium in the solar system are two-fold:

- a) The measurements of D/H in the methane present in the atmospheres of Uranus, Neptune and Titan corroborate the assumption that there are two different reservoirs of deuterium in the solar system which were established before its formation: that contained in gaseous hydrogen (as now found in the atmospheres of Jupiter and Saturn), and that contained in the volatiles which have been trapped in cold, solid material (Owen et al, 1986). The D/H ratios measured in the methane of Titan, Uranus and Neptune characterize this second reservoir.
- b) The observed enhancement of D/H on Mars, compared to the terrestrial value, is another indication (in addition to geological evidence) that the Martian atmosphere must have been denser and warmer in the past and large amounts of liquid water could have once been on the planet (Owen et al, 1988).

The observations made at CFH have provided additional results which were not expected and which are the source of separate studies:

- On Venus, the detection of a strong CO emission at 4.8 μm , apparently due to a mechanism of fluorescence in the upper atmosphere.
- On Neptune, the detection of important spectral variations of the scattered sunlight at the bottom of the strongest methane bands, which can be interpreted as the signature of important inhomogenetics in the poorly known Neptune atmosphere. This behavior, which we were able to follow for 3 nights, contrasts with Uranus which exhibits a comparable but very stable spectrum.

C. de Bergh, J.P. Maillard

REFERENCES

C. deBergh, B.L. Lutz, T. Owen, J. Brault, J. Chauville, *Monodeuterated methane in the outer Solar System. II. Its detection on Uranus at 1.6 microns*, *Astrophys. J.*, 311, p. 501, 1986.

T. Owen, B.L. Lutz, C. deBergh, *Deuterium in the outer Solar System: evidence for two distinct reservoirs*, *Nature*, 320, p. 244, 1986.

C. deBergh, B.L. Lutz, T. Owen, J.P. Maillard, *Neptune: short-term variations in the spectrum at 1.6 microns and the search for deuterated methane*, *B.A.A.S.*, 19, p. 864, 1987.

C. de Bergh, B.L. Lutz, T. Owen, J. Chauville, *Monodeuterated methane in the outer Solar System. III. Its abundance on Titan*, *Astrophys. J.*, in press.

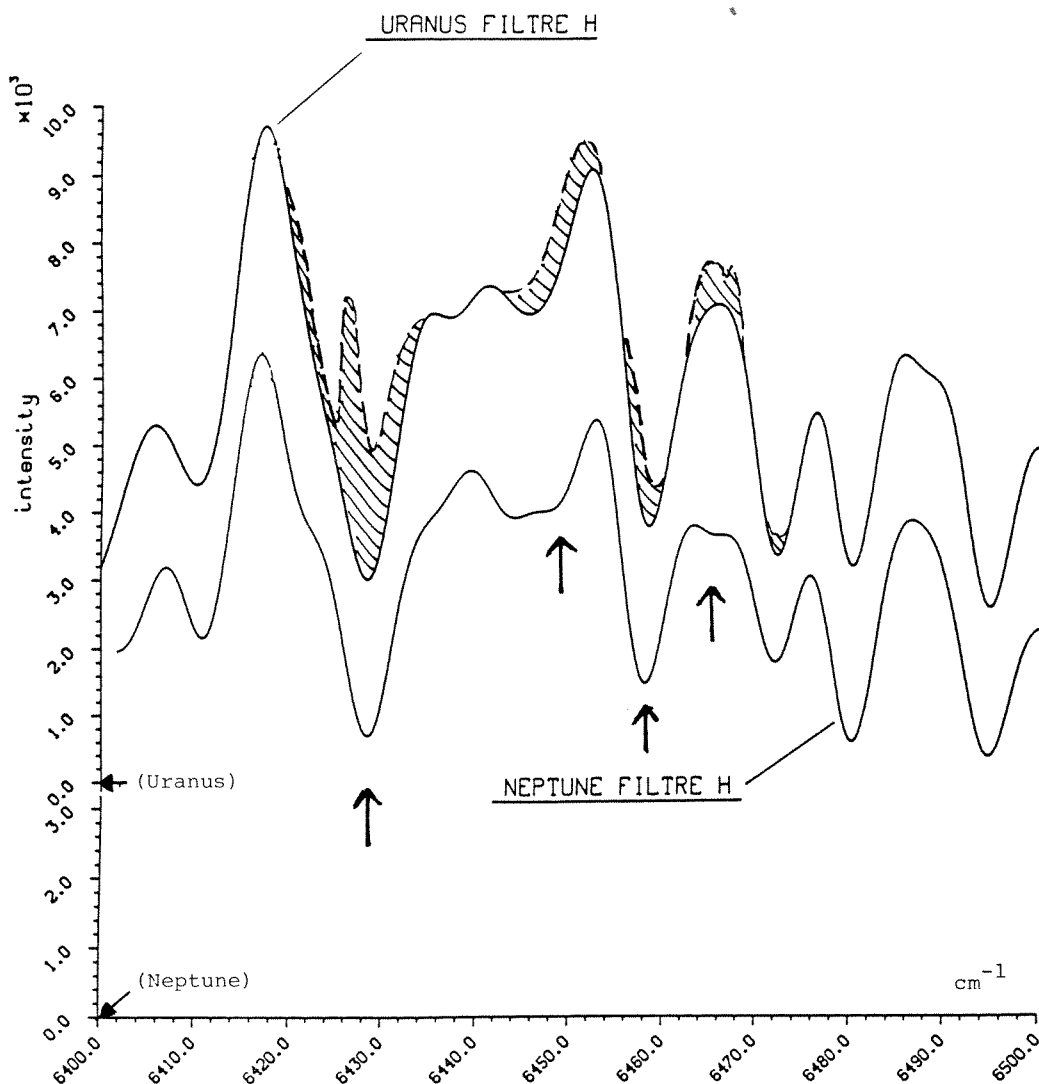


Figure 1: Extracts of spectra of Uranus and Neptune recorded with the FTS at the CFH telescope in July 1987. The spectral resolution is 4 cm^{-1} . For Uranus (magnitude: 7.6 at 1.6 μm), a signal-to-noise ratio of 59 was obtained in 11 hours and 15 minutes.

The arrows indicate regions of absorptions in the $3\nu_2$ band of CH_3D . From left to right: the Q-branch, the R2, R3 and R4 manifolds. Hatched areas in the Uranus spectrum correspond to the contribution of CH_3D to the absorption. The remaining absorption is entirely due to ordinary methane. We have found from these spectra that the D/H ratio in the methane of Neptune is only slightly higher than the one in Uranus, and is very close to the ratio found in standard terrestrial ocean water (SMOW), namely 1.5×10^{-4} .