The instrument works in two modes: in the standby mode, where the internal clock is running and the output for telemetry activated, and in the experiment mode, where the image intensifier is turned on and the camera is working. Several housekeeping parameters are transmitted by telemetry at slow rate: the status of standby and experiment power, image intensifier current, temperature of the film magazine, protective shutter status, day sensor status, temperature status, and stepping motor status (film advance). The scientific data were stored on the film, which is a good medium for information storage. The use of film rather than a television system saved 10^5 bits per second when the instrument was operating.

Flight and preliminary results. For the flight we chose to take a picture every 16 seconds with alternate exposure times of 0.6 and 1.2 seconds. It was possible to adjust these times by changing straps. The exposure times were expected to be approximately the given ones with the factor of 2 providing some margin. The time between two frames allowed a good overlap of pictures with enough film for the overall flight. The instrument was activated by the Command and Data Management System (CDMS) according to the time line of the experiment. For protection in case of failure of the time line, a light detector would turn off the instrument if the illumination was greater than 2 lux. The crew monitored the temperature and were instructed to turn off the instrument if it was higher than 40°C (which could destroy the image intensifier) or less than −20°C (which could break the film, which is brittle at low temperatures). During the flight the instrument was on during 27 orbits, for a total duration of 528 minutes, and worked perfectly. Extra observations were possible for the study of the shuttle glow. On the whole, 1771 pictures were taken. Unfortunately, the delayed launch date resulted in unfavorable orbits. We expected to make observations between latitudes 57°S and 57°N, but coverage was reduced at best ±35°. The observations during the last orbits were very short and the images were fogged by sunlight scattered at the earth's limb. However, the observations covered a total useful surface of about 2×10^8 km^2 (40 percent of the earth's surface) and should be good for study of the OH structures at low latitudes.

The results are good. Some pictures (Fig. 3) show band-type structures. Only part of the earth appears to be covered by these structures, as we expected from our statistics obtained on the ground.

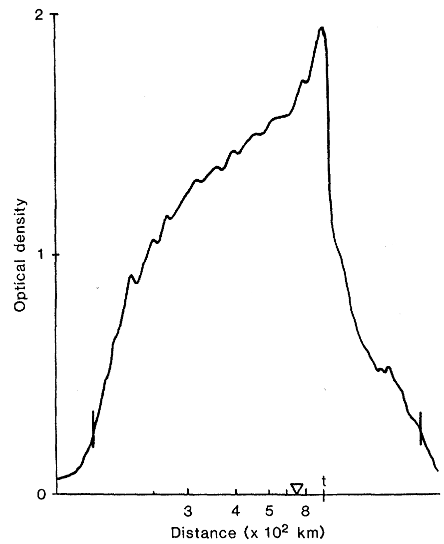

Fig. 4. Microdensitometer tracing along a diameter of Fig. 3. The ordinate is the optical density of the negative. The abscissa is the distance to the subsatellite point at the altitude of 85 km. The triangle indicates the earth's limb.

Figure 4 is a microdensitometer tracing across Fig. 3. We see the strong increase in brightness when the layer is seen tangentially. This increase, due to the larger geometrical optical path, is called the van Rhijn effect. We also see the modulation of the OH wave. In the data processing, classical image processing will be used to enhance contrast and the structures will be projected in geographic coordinates.

Conclusion. The OH emission structures have been observed from space. The shuttle appears to be a perfect platform for our instrument, providing favorable environmental conditions, good flexibility in operation, and the possibility of film recovery. The results will be used to draw a map of the waves near the 85-km level and to attempt to distinguish between interface and gravity waves.

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Observations of Lyman-α Emissions of Hydrogen and Deuterium

Abstract. *A spectrophotometer was flown on Spacelab 1 to study various mechanisms of Lyman-α emission in the upper atmosphere. The use of absorption cells filled with H_2 and D_2 gases allowed us to discriminate a number of weak Lyman-α emissions heretofore masked by the strong H geocoronal emission due to resonance scattering of solar photons. Preliminary results are presented on three topics: the first optical detection of the deuterium Lyman-α emission at 110 kilometers, with an intensity of 330 rayleighs indicating an eddy diffusion coefficient of 1.3×10^6 square centimeters per second; auroral proton precipitations seen on both the night and the day side; and an emission located above 250 kilometers of altitude, interpreted as the result of charge exchange of magnetospheric protons with geocoronal atoms.*

As part of the European payload complement, a Lyman-α spectrophotometer (experiment 1ES017) was flown on the Spacelab 1 mission in November and December 1983. The observations provide data on atmospheric hydrogen and deuterium atoms, auroral proton precipitations, and a newly observed phenomenon attributed to a "hot" hydrogen emission.

These Lyman-α emissions, whose sources are shown schematically in Fig. 1, can be distinguished from each other by their spectral characteristics. The most intense emission [intensity $I_H \sim 20$ kilorayleighs (kR)] comes from the resonance scattering of solar photons by atomic hydrogen in the geocorona at 121.566 nm, which was thoroughly studied by a number of space experiments (*1*, *2*) in the period 1965 to 1972. Therefore, our main objectives with the present Lyman-α spectrophotometer were to observe other sources of Lyman-α emission. The resonance scattering of deuterium atoms at 121.533 nm is well separated from the hydrogen Lyman-α emission at 121.566 nm. Its intensity, I_D, however, is expected to be much lower as a consequence of the low deuterium-to-hydrogen ratio, which is 1.6×10^{-4} in seawater (*3*). In addition, Lyman-α emission can be produced when fast protons exchange charge with neutral species. In this case, the spectral width is much larger than the geocoronal emission. Such emission was expected in the auroral regions and was observed. However, in the equatorial regions, as well as during combined observations with the plasma ejector active experiments on Spacelab 1, we could not identify in the preliminary analysis Lyman-α emission due to charge exchange.

The apparatus, which weighed 13 kg, was constructed jointly by France and Belgium in our laboratories and functioned flawlessly during the 10-day mission. It was operated for a total of 35 hours, covering 44 periods of observation in various configurations of the spacecraft attitude and internal modes of functioning. With this lightweight spectrophotometer (*4*), a scanning mirror makes it possible to observe the emission in a plane perpendicular to the longitudinal axis of the spacecraft, above the door of the cargo bay. A spectrometer isolates a bandwidth of 4.5 nm around Lyman-α and thus eliminates the strong 130.4-nm atmospheric emission of atomic oxygen. The light passes through two absorption cells filled with molecular hydrogen and molecular deuterium, respectively (*5*). Photons are detected with a solar blind photomultiplier.

The instrument was controlled by the "brain" of Spacelab, the Command and Data Management System (CDMS), which sent one command each second to the instrument for the selection of mirror position, cell status, and other instrument parameters. These commands were issued according to a software program, reading a table specific to the type of observation. New tables could be drawn up during the mission and sent to Spacelab, in reaction to the first results returned in real time or playback mode. The overall operation of this complex system, the combination of Spacelab and orbiter, was found to be quite flexible but also very demanding for the investigators.

The mission was extended to a tenth day, which allowed us to make an unscheduled observation of Lyman-α emission toward the zenith. As a result we observed an unexpected feature, which we attribute to nonauroral charge-exchange emission, as will be discussed below.

Auroral observations. Figure 2 shows the raw data obtained by our ground

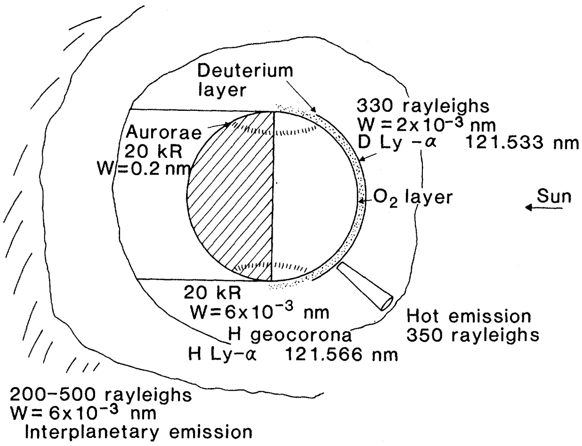

Fig. 1. Sources of Lyman-α emission observed during the Spacelab 1 mission. The most intense emission is the resonance scattering of solar photons by hydrogen atoms in the geocorona. A hydrogen absorption cell was used to eliminate most of this emission in order to study the other sources. Emission by deuterium atoms was detected for the first time, just above the altitude where O_2 absorbs. Aurorae produced by proton precipitation were detected in the northern and southern hemispheres, on both the night side and day side. A "hot" emission, not absorbed by the hydrogen cell, was observed when looking upward from the orbiter's altitude of 250 km.

support equipment during the flight. In this typical situation, the orbiter was flying horizontally like a plane upside down. The mirror was moving in a plane perpendicular to the velocity vector, which ensured zero Doppler shift between the atmospheric emission and the H_2 and D_2 absorption cells (otherwise there would be no absorption). For most of time the scanning covered the limb region, where a line of sight passes just above 110 km in altitude, where Lyman-α absorption by O_2 becomes negligible. Except when an excursion was made in the nadir direction, the hydrogen absorption cell was activated. The count rate is plotted in the lower part of Fig. 2. Up to time t = 1100 seconds, a small increase in the signal is observed whenever the line of sight crosses the limb, at α = 78° from the nadir. Later, increasingly strong peaks appear, which can be very narrow and reach an intensity greater than 15 kR. These additional peaks are Lyman-α emission not absorbed by the hydrogen cell. They are attributed to ion-neutral charge exchange of multi-kilo-electron volt protons precipitating in the auroral zone. During the mission, aurorae were observed in both the northern and southern hemispheres and on both the night and day side. We believe these are the first observations of daytime auroral emission at Lyman-α.

Detection of deuterium. We have reported (*4*) the first optical detection of deuterium in the upper atmosphere. An emission intensity of 330 rayleighs was deduced at an altitude of 110 km. This intensity corresponds to a column density of 2.2×10^{11} atoms cm^{-2} for deuterium along the line of sight. Since the homopause height, at which the vertical distribution of deuterium deviates from the main atmospheric constituents, depends on the eddy diffusion coefficient

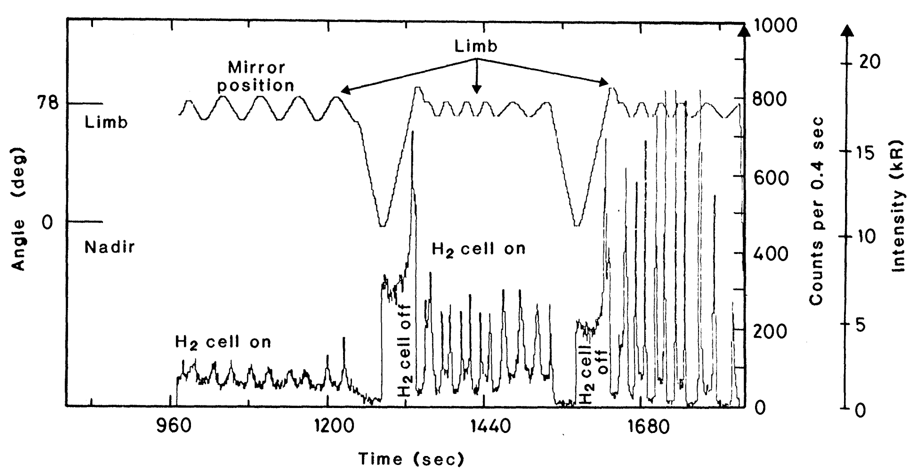

Fig. 2. Raw data recorded in real time as a function of time elapsed from the beginning of a run. The mirror position is indicated on the upper curve. Scans were made around the limb at α = 78° and the hydrogen cell was always operated, except for two excursions to the nadir direction. After 1200 seconds increasingly intense peaks appear each time the line of sight crosses the limb. The emission, which can go through the hydrogen cell without being absorbed because it is spectrally very wide, is attributed to auroral activity at 60° latitude in this example. Several other observations were obtained during this mission.

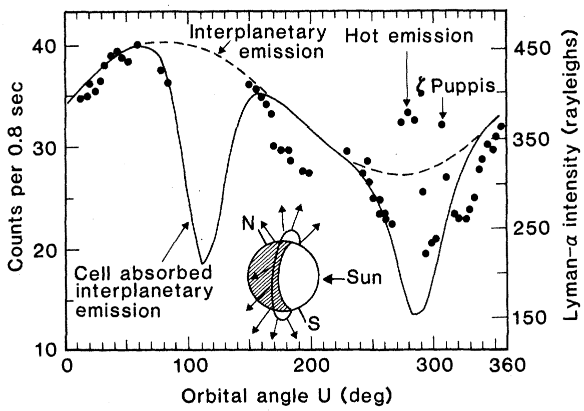

Fig. 3. Unexpected observation during the extended mission. With a proper attitude of the orbiter the line of sight was kept vertically toward the zenith. The hydrogen cell was continuously operated along a full orbit and the intensity which was not absorbed is plotted as a function of orbital angle U (the missing data were collected but are not yet available). Angle $U = 0^0$ corresponds to the orbital ascending node. Looking upward, the hydrogen Lyman-α geocoronal signal is totally absorbed by the H_2 cell and what remains is principally the interplanetary signal; a model of this is fitted to the data points (dashed line, H_2 cell off; solid line, H_2 cell on). Two unexpected peaks appear between $U = 250°$ and 300°. The narrow one is due to the bright ultraviolet star ζPuppis; the broader one is probably due to Lyman-α emission produced by charge exchange of protons with geocoronal neutral hydrogen. Such a small emission (~ 350 rayleighs) could not have been detected if the usual strong geocoronal Lyman-α had not been eliminated by the H_2 absorption cell.

K, a simple model (*6*) allowed us to derive from the deuterium measurement an estimate of $K = 1.3 \times 10^6$ cm^2 sec^{-1}. The D/H ratio at 110 km is 3×10^{-4}, a modest enrichment compared to the D/H ratio of 1.6×10^{-4} at sea level.

The Lyman-α technique used for the observation of deuterium emission will also be applicable for observing the upper atmosphere of other planets, either with orbiting space probes or with the space telescope. Such measurements should yield valuable data related to the history of water on Mars and Venus (*7*).

Although we have demonstrated on this first Spacelab mission the validity of our method for deuterium detection, we encountered two problems. One is that the sensitivity was a factor of 4 below its nominal value, and it was not possible before flight to switch to a more sensitive unit. The second is that the orbit was far from ideal for deuterium observations. Owing to the launch date the spacecraft shifted rapidly toward a full sun orbit, so that the orbiter was always very near the terminator, where excitation of deuterium atoms by solar Lyman-α photons is decreased by a larger O_2 column density. As a result, the deuterium emission (*4*) could be observed only during the first 24 hours of the 10-day mission. Another mission will be needed to determine a variation of the homopause level with latitude, a major atmospheric objective.

Hot hydrogen emission. An observation that was not planned originally yielded a result which is not yet fully understood. On the tenth day of the extended mission, the orbiter was flying like a plane and the line of sight was oriented toward the zenith (Fig. 3). The H_2 absorption cell was activated at its highest possible level (optical depth ~ 600), and practically all the geocoronal zenith Lyman-α emission was absorbed since the Doppler shift was zero. The remaining intensity which was not absorbed is shown by the data points in Fig. 3 as a function of the orbital angle U, a full orbit giving a full scan over a great circle of the celestial sphere. The solid line was obtained with a model of the interplanetary emission, scaled linearly to fit the data around $U = 0^0$ (*8*). Besides the overall sinusoidal variation of the model of the interplanetary emission which would have been observed if the H_2 cell had not been activated (dashed lines), the model predicts that absorption by the H_2 cell should occur in two regions, where the Doppler shift is zero with respect to the flow of interplanetary atoms of interstellar origin. At present, we have only the data which were collected in real time during the mission, but eventually a full scan will be completed. The limited data coverage shows a very good fit to the model, except in the region of the trough around $U = 280°$. Two peaks are present. The narrow peak has been readily identified as due to the presence of the bright ultraviolet star ζPuppis in the field of view, whereas the peak ~ 20° wide does not correspond to any known celestial source. Since a Lyman-α photometer flown on the Soviet Prognoz 5 and Prognoz 6 at 200,000 km did not show such a phenomenon, we conclude that this emission does not come from a celestial source but is generated in the earth's environment. Celestial coordinates were right ascension α = 72° and declination δ = −57°; geocentric coordinates were latitude 57°S, longitude 20°E, local time 20 hours.

We suspect that this emission, which must be spectrally wide since it is not absorbed, is produced in the upper atmosphere by charge exchange between magnetospheric protons and hydrogen atoms from the geocorona. Why it is localized in a narrow region is a question which will need a more elaborate analysis.

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