roads with a width of 10 m or more can be recognized on the black-and-white photographs. Figure 2 shows a tenfold enlargement of the original image taken over the city of Munich in the Federal Republic of Germany. Nearly every street is visible as well as major buildings. From preliminary results it can be expected that photomaps at the scale 1:100,000 can be produced from the metric camera photographs.

The color infrared images can also be used to produce 1:100,000 photomaps. In addition, they will mainly be useful for land-use interpretation in the countries of the Third World. For example, Fig. 3 shows the Al Gezira area of Sudan with the White Nile on the left and the irrigated fields by the Blue Nile at the right in contrast with the desert.

Many black-and-white photographs were taken at extremely low sun angles over North America. Nevertheless, they reveal the morphology of the terrain, especially in arid zones, and may be suitable for geological studies (Fig. 4).

Mapping will also be carried out by stereophotogrammetric techniques, producing topographic maps with 50-m contours.

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References and Notes

1. Analysis of the results of this experiment, in which over 100 institutions are participating worldwide, will be presented in preliminary form at the International Congress for Photogrammetry and Remote Sensing in Rio de Janeiro in June 1984 and in final form during a user symposium in late 1984 in the Federal Republic of Germany. There is great expectation that the camera experiment has provided an economical and efficient mapping tool leading to new and unique observation of the earth's surface.

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Atmospheric Spectral Imaging

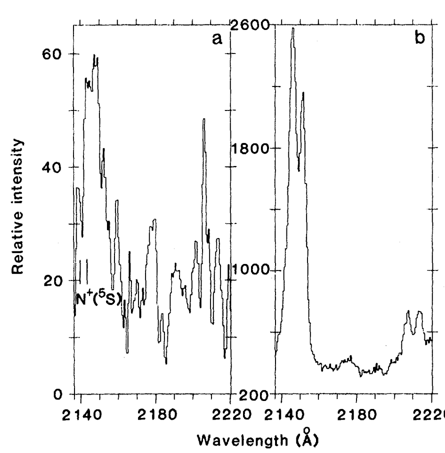
Abstract. *An array of imaging spectrometers flown on the Spacelab 1 mission was capable of providing spectra of the atmospheric emissions over a broad wavelength range from 300 to 12,700 angstroms and acquiring each complete spectrum nearly simultaneously. The instrument was used to make observations on the day side and night side of the earth, looking down in the nadir direction, radially away from the earth, and in various limb-scanning modes. Observations were made looking at various angles to the vehicle velocity vector and during thruster firings and water dumps as well as at times when such events were inhibited. As a result of the mission a data base has been acquired that is valuable for studies of both the upper atmosphere and the shuttle-Spacelab vehicle environment.*

During the mid-1970's developments in ionospheric and thermospheric physics indicated a need for multispectral measurements over a relatively broad region of the optical spectrum. Measurements of atmospheric emissions in the ultraviolet, visible, and near infrared contain significant information concerning concentrations of species, solar and magnetospheric energy influx, and the ensuing chemical and radiative processes. Such measurements made from an orbiting space platform can provide the dependence of these parameters on altitude, latitude, and longitude, provided the data are acquired in a time period that is short compared with the typical 90-minute orbiting period of the vehicle. The opportunity to design an instrument capable of operating over such a wide wavelength range and measuring relatively low light levels in a suitably short time interval was provided by the payload capacity of the shuttle-Spacelab system.

Such an instrument was flown on the Spacelab 1 mission (28 November to 6 December 1983) and is called the imaging spectrometric observatory. The instrument consists of an array of five spectrometers, each of which covers a portion of the spectrum from 300 to 12,700 Å. The five spectrometers operate in parallel and each has a focal-plane detector which is optimized for a particular region of the full spectral range and which comprises an intensified two-dimensional charge-coupled device array. The spectrum is imaged in one dimension and spatial information (corresponding to the length of the entrance slit of the spectrometer) is imaged in the other. The five spectrometers are located on the instrument pallet in the shuttle cargo bay, and a dedicated microcomputer system, which acts as the array controller and data handler, is located in the Spacelab module. The instrument has been described in detail (*1–3*).

The primary scientific objectives of the instrument on the Spacelab 1 mission were as follows (*4*): to survey the emission spectrum of the atmospheric dayglow over the range 300 to 12,700 Å; to obtain limb scan profiles of these emissions (particularly in the vacuum ultraviolet); and to make observations over a wide variety of vehicle orientations and solar illumination conditions in order to assess the suitability of the Spacelab-shuttle system as a platform from which to make such optical measurements.

During the course of the 10-day Spacelab 1 mission, the imaging spectrometric observatory operated on 60 different occasions for periods ranging from 8 minutes to over 9 hours. A fairly extensive data base was acquired and, as the data rate of the instrument is 125 kilobits per second, the volume of data acquired is very large. The instrument is highly programmable but essentially measures 12,400 Å of the spectrum at 3- to 6-Å spectral resolution every few minutes.



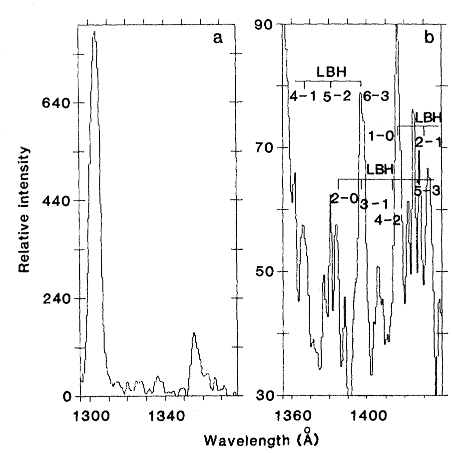


Fig. 1 (left). Spectral segment from dayglow limb scan experiment showing two points in the scan corresponding to approximately (a) 235 km and (b) 90 km. Fig. 2 (right). Two spectral segments from dayglow limb scan.

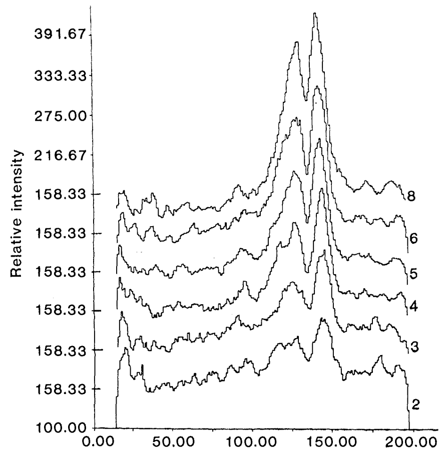


Fig. 3. Illustration of simultaneous spectral and spatial imaging. The spectrometer entrance slit is centered at approximately 90 km and resolved into eight horizontal segments spanning 0.65°, with row 8 being deepest in the atmosphere. Pixel 200 corresponds to 7511.8 Å and pixel 20 corresponds to 7825.4 Å. The feature shown is the 0–0 band of the O_2 atmospheric system to 7620 Å.

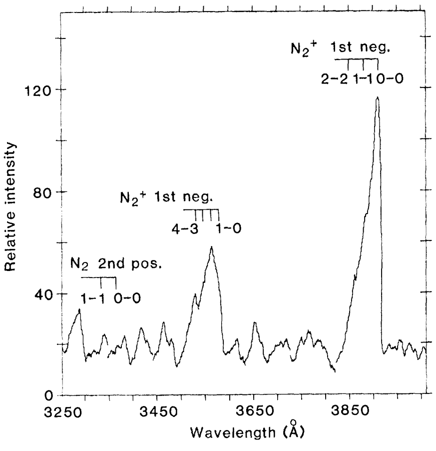


Fig. 5. Illustration of relative magnitudes of N_2^+ first negative and N_2 second positive bands during the experiment referred to in Fig. 4.

At the time of writing only a relatively small fraction of the measurements have been processed to the stage of spectra. In addition, we do not yet have the ancillary data that contain the information on vehicle attitude and position and times of such events as thruster firings and water dumps necessary for correlation with the measurements. Thus in this report we will present a selection of the results that have been looked at to date and that can be condensed into a few illustrative figures. It should also be mentioned that the data processed so far are entirely from those recorded in real time by our ground support equipment during the mission and thus are incomplete and discontinuous. We are now receiving the mission data tapes recorded by NASA, which were subsequently processed into a chronological and continuous set more suitable for analysis.

Some preliminary results. In the first of the primary objectives mentioned above, namely a survey of the emission spectrum of the upper atmosphere with principal emphasis on the sunlit atmosphere, the mission must be considered relatively successful. Data were taken over the full spectral range of the instrument on the day side and night side of the earth and distributed over the latitude range 57°S to 57°N covered by the Spacelab 1 orbit. While some of this data set will provide more information on vehicle effects than atmospheric physics, enough has been obtained to plan optimized studies on future missions and to demonstrate the successful design performance of this new class of instrument.

The major goal of obtaining limb scans of dayglow emission features was met to a large degree. This was accomplished by two techniques. The first involved a planned roll of the shuttle so as to scan the field of view down through the atmosphere at a controlled rate while the instrument repeatedly scanned in wavelength. Some examples of the results are shown in Figs. 1 and 2. Figure 1 shows the spectral segment from 2135 to 2220 Å for a point in the scan corresponding to a tangent ray height near 235 km and another near 90 km. The emergence of the nitric oxide 1–0 gamma band at 2148 Å can be seen. Also seen in the higher-altitude portion of Fig. 1 is the $N^+(^5S)$ doublet at 2143.6 and 2139.7 Å, known for several years as the mystery feature. Figure 2a shows the spectral segment containing the atomic oxygen features at 1304 and 1356 Å. Also seen is a feature near 1365 Å. As the field of view is scanned down through the atmosphere this feature becomes relatively large, and we have not yet identified it. Figure 2b shows the adjacent grating step. The feature can again be seen together with the Lyman-Birge-Hopfield bands at longer wavelengths.

A second method of obtaining altitude information on the day side involved the fact that the instrument is capable of imaging spatially along the length of the slit. Thus if the vehicle is oriented so that the entrance slit of the instrument is perpendicular to the limb of the earth, a height segment of approximately 16 km is obtained resolved at 2-km intervals. An example of this technique appears in Fig. 3, which shows the 0–0 atmospheric band of O_2 for a simutaneously acquired altitude segment centered near 90 km. This method provides simultaneous spectral and spatial imaging of atmospheric emissions from space and represents a powerful technique for future studies. In addition to the day-side measurements, altitude profiles were obtained on the night side with a scanning mirror. These data have yet to be processed.

In the area of shuttle environment, a most valuable data base has been obtained. A careful correlation of vehicle attitudes and vehicle-related events with background level and features within the spectrum will be conducted over the next several months. Only one aspect will be commented on here. On the tenth day of the mission, an observation sequence was added in which the shuttle flew with the payload bay ($-z$-axis) into the velocity vector. The imaging spectrometer array was configured to make

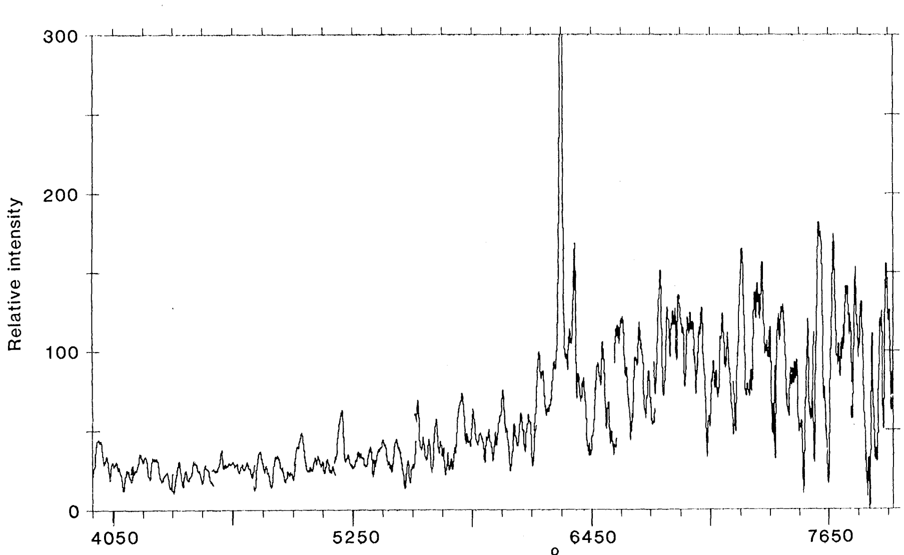


Fig. 4. Condensed display of spectrum acquired by visible channel during a period of observations into the velocity vector.

measurements looking forward into the velocity vector away from the vehicle. The field of view of the instrument is very small (0.65° by 0.01°) and thus it looked tangentially away from the earth at 250 km with no possibility of viewing either shuttle surfaces or the earth or lower atmosphere. The measurements were made under sunlit conditions, with the plane of the orbit close to the terminator. The experiment was designed to look into possible emissions associated with atmospheric interactions with surfaces or shuttle environment (*5*). A significant enhancement was found to exist longward of 6000 Å, as shown in Fig. 4. The enhancement consists of a number of different overlapped molecular bands, which are in the process of being identified. The spectrum was found to be noticeably lacking in atomic features. One of the theories proposed to date to explain shuttle glow effects involves a plasma discharge mechanism, with the source of the emission being impact by energetic electrons (*6*). The spectra show pronounced N_2^+ first negative bands, which might at first appear to support this theory except that the N_2 second positive system, which has a large cross section for impact excitation, is practically if not completely missing. This is illustrated in Fig. 5. A mechanism must thus be found which is capable of ionizing N_2 while not exciting the second positive system. This topic will be discussed in greater detail elsewhere (*7*).

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Sample Performance of the Grille Spectrometer

Abstract. *The grille spectrometer observed the setting and rising sun 18 times during the Spacelab 1 mission. In addition to solar absorption lines, many of which had not been observed before, atmospheric spectral absorptions due to carbon monoxide and carbon dioxide were observed at heights tangent to the thermosphere (greater than 85 kilometers), and absorptions due to ozone, water, methane, and nitrous oxide were observed in the mesosphere (greater than 50 kilometers). The strongly coupled molecules NO-NO$_2$ and HCl-HF were observed as pairs in the stratosphere. Methane is presented as an example of the instrumental operations because of the characteristic aspect of the* Q *branch of its* v_3 *band.*

Infrared absorption spectrometry of the atmosphere, using the sun as a light source at sunrise or sunset, has for the past 15 years proved to be a powerful method of studying vertical distributions of trace species (*1*). The largest possible amount of light-absorbing molecules is observed on the optical path tangent to the earth's surface at various altitudes, allowing the deconvolution of very low concentrations as a function of altitude. A great deal of information has already been gathered with this method from high-altitude platforms such as aircraft and balloons. An orbiting platform provides access to higher altitudes and to nearly global coverage. Whereas with high-altitude platforms the earth's rotation provides altitude scanning at sunrise or sunset, scanning is achieved at a much higher rate from an orbiting spacecraft. Such fast spectral scanning requires a high-throughput instrument.

The choice of instruments satisfying the requirements for scanning from orbit is limited (*2*). The grille spectrometer (*3*) is well adapted, as demonstrated by the first Spacelab flight. A single grille mounting was selected to act as entrance and exit light ports for the spectrometer. The instrument and its operation (*4*) are described briefly as follows.

The optics consists of a two-axis steerable frontal plane mirror which tracks the sun in front of a Cassegrain telescope with aperture 30 cm and focal length 6 m. The sun is imaged on the grille, which intercepts a square portion of the solar image (8 arc minutes). The spectrometer has a grating of 59 grooves per millimeter, which is illuminated by a parabolic mirror oscillating at 436 Hz with an amplitude of ±20 arc seconds; the position of the mirror is controlled within 5 arc seconds. The exit light flux, split into two beams, passes through interference filters to two detectors (InSb, 2.5 to 5.5 μm, and HgCdTe, 2.5 to 10.5 μm). The spectral resolving power is 1.3×10^4 (instrumental line width at half peak height).

The electronics in the Spacelab module links the pallet instrument to the Command and Data Management System (CDMS) and the high-rate multiplexer (HRM). Using data originating from the orbiter (time, attitude, and orbit parameters) and from Spacelab (time line, onboard and ground commands, sun ephemeris), it manages the execution of the stored measurement programs, including inflight updating. The electronics on the pallet instrument provides the functions of electromechanical control and signal detection and formatting. The main role of the crew was to check the instrument wavelength calibration, spectral resolution, and sensitivity by monitoring the display of a calibration spectrum generated inside the spectrometer with a calibration lamp shining through a gas cell. The mission specialist in charge of this task performed a wavelength alignment 12 hours after launch.

The pallet instrumentation weighed 122.8 kg, was 1.8 m high, and occupied 0.7 m^2. The weight of the module equipment was 15 kg. The data rate in operation was 51.6 kilobits per second.

Twenty-five solar occultation runs were allocated for this experiment on Spacelab 1. Because of the launch window time-season combination the runs were scheduled in the first days of the mission since the full orbit was in sunlight during the last 5 days. Observations at sunset took place in the northern hemisphere at latitudes ranging from 56°

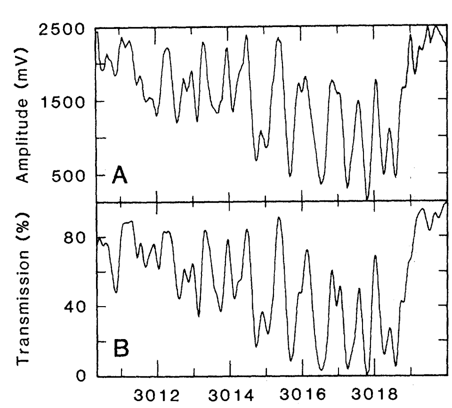

Fig. 1. (A) Spectrum of the *Q* branch of the 3.3-μm band of CH_4 recorded in 2 seconds on 3 December 1983 at 3 hours, 47 minutes, 49 seconds Greenwich mean time. The signal amplitude is plotted against wavenumber. (B) Synthetic spectrum of the same absorption feature computed with the Air Force Geophysical Laboratory molecular parameters (*5*) and the CH_4 vertical distribution deduced from the spectra.