GOME: A New Instrument for ERS-2

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The Global Ozone Monitoring Experiment, or GOME, is a new instrument that will be added to the original ERS-1 payload complement for the launch of the second European Remote-Sensing Satellite (ERS-2) in 1994. GOME is a nadir-viewing spectrometer which will observe solar radiation transmitted through or scattered from the Earth's atmosphere or from its surface. The recorded spectra will be used to derive a detailed picture of the atmosphere's content of ozone, nitrogen dioxide, water vapour, oxygen/oxygen dimer and bromine oxide and other trace gases. ERS-2's orbit will provide global Earth coverage every three days.

Introduction

In 1989, ESA decided to continue the ERS Programme beyond the expected lifetime of the ERS-1 satellite by approving the building and launch of the ERS-2 satellite. To provide the necessary continuity to the observations started by the instruments of ERS-1, ERS-2 is essentially a carbon-copy of the ERS-1 satellite. It was recognised, however, that there is an urgent need to investigate the composition and dynamic behaviour of the Earth's atmosphere. The ERS-2 Programme approval therefore included an experimental sensor for atmospheric research, the 'Global Ozone Monitoring Experiment' (GOME), which is essentially a scaled-down version of the SCIAMACHY instrument proposed for the European Polar Platform to be launched at the end of the century.

The inclusion of the GOME sensor in ERS-2 Programme was endorsed on the explicit understanding that:
- the sensor would be developed, tested, calibrated and integrated in the same time frame as the satellite and the other instruments would be rebuilt
- the resource demands of the sensor would have to be satisfied from the existing system margins, imposing stringent limitations on mass, power and data rate
- no major upgrades in the ERS Ground Segment would be needed, and the financial burden for the data-processing algorithms and software would be borne by scientific institutions and/or national agencies.

The limitations on resources have already led to drastic changes in the instrument concept, because at the Baseline Design Review held in February 1991 it became obvious that the power/energy demand exceeded the available margin. Instead of GOME having its own interface to the On-Board Computer (OBC) and to the Instrument Data Handling and Transmission (IDHT) system, it was decided to provide these functions via the existing interfaces of the Along-Track Scanning Radiometer (ATSR) instrument.

Scientific objectives

Ozone (O_3) is a tri-atomic form of oxygen, formed by hard ultraviolet radiation in the atmospheric layer between about 15 and 45 km altitude, the so-called 'stratosphere'. It absorbs radiation in the spectral region between 240 and 310 nm, preventing these harmful rays from reaching the ground in large quantities. This naturally protective atmospheric layer is now being threatened by human activities, in particular by the steady release of chlorfluorocarbons (CFCs) into the atmosphere. The accumulated anthropogenic effects on stratospheric ozone are believed to be causing a steady depletion of the ozone layer by approximately 0.3 % per year.

The chemistry of the stratosphere is very complex. The hard ultraviolet radiation causes the breakup of many of the available species into reactive fragments, which lead to a multitude of possible reactions. Normally, the rates of these reactions depend not only on the nature of the species, but also on local pressure, temperature, radiative fluxes in the different wavelength regions, vertical and horizontal transport processes, etc. Thus, in order to understand the ozone chemistry fully, it is not sufficient just to measure the ozone; one must also monitor the abundances of many other species, including very

reactive intermediate species occurring in only very low concentrations.

Reflecting this need, GOME is intended to measure other species as well as to observe aerosols and polar stratospheric clouds which play significant roles in the heterogeneous processes associated with ozone chemistry. It is hoped that some of these species may be observed in the troposphere, another part of the atmosphere believed to be affected by man's activities. However, the presence of clouds may make this difficult.

For this GOME will exploit spectroscopy, which is a viable technique for observing trace species in the atmosphere. Sunlight, reflected by the ground surface and scattered within the different atmospheric layers, carries the absorption signatures of the absorbing species (Figs. 1 & 2). The GOME instrument is designed to collect this light over the entire wavelength region from 240 to 790 nm, in which not only ozone, but also a number of other atmospheric species absorb. In addition to the classical backscatter technique, the GOME instrument exploits the novel technique of 'Differential Absorption Spectroscopy' (DOAS)*.

Satellite mission and instrument accommodation

Like its predecessor ERS-1, ERS-2 will fly in a Sun-synchronous polar orbit with an inclination of 98°, with a mean altitude of 780 km and a local time of 10.30 h for the equator crossing on the descending node. This results in an orbital period of approximately 100 min and a ground speed for the subsatellite point of 7 km/s.

The GOME instrument's instantaneous field of view has been chosen to be 40 km x 2 km, or 2.8° x 0.14°. Via the

* Developed by U. Platt (Heidelberg, FRG).

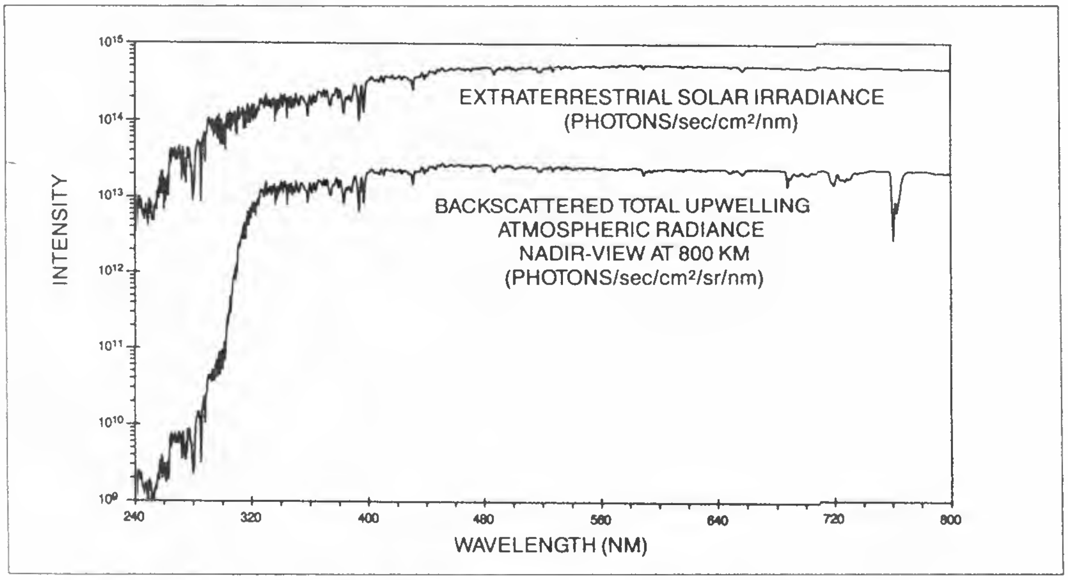


Figure 1. LOWTRAN simulation of spectral radiances at the top of the atmosphere in the wavelength range of the GOME instrument, i.e. 240–790 nm

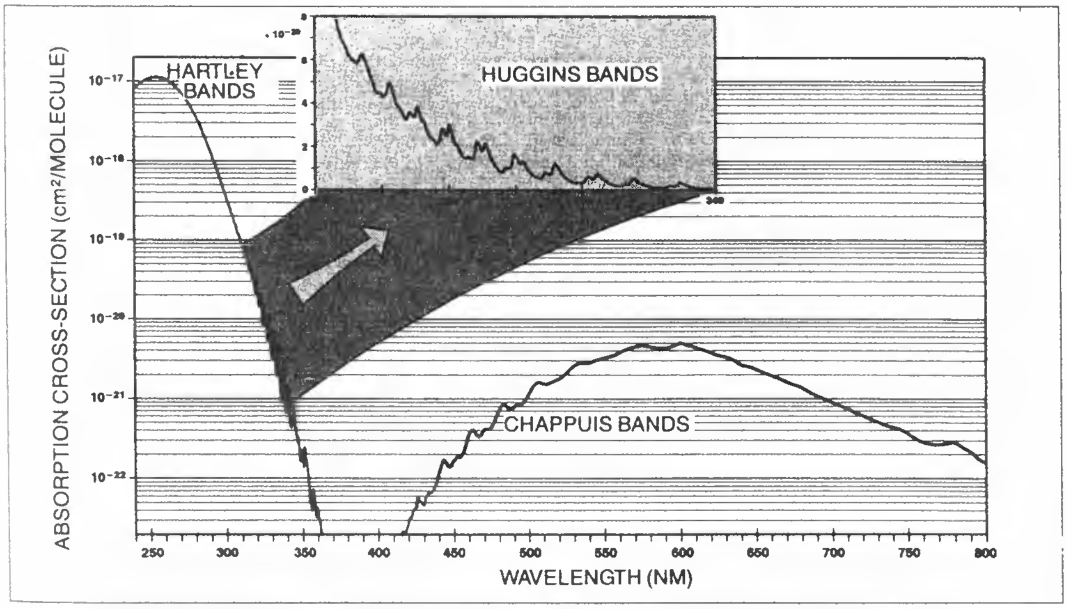


Figure 2. Ozone absorption cross-sections in the wavelength range of the GOME instrument

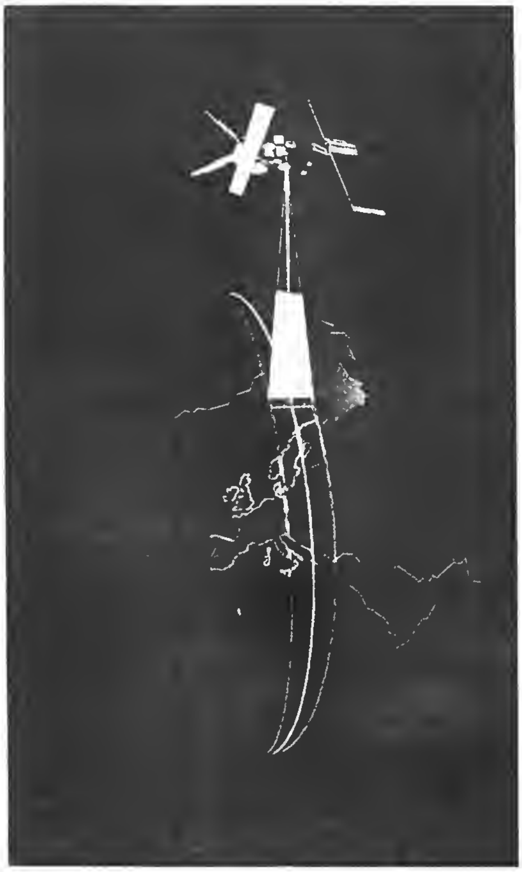
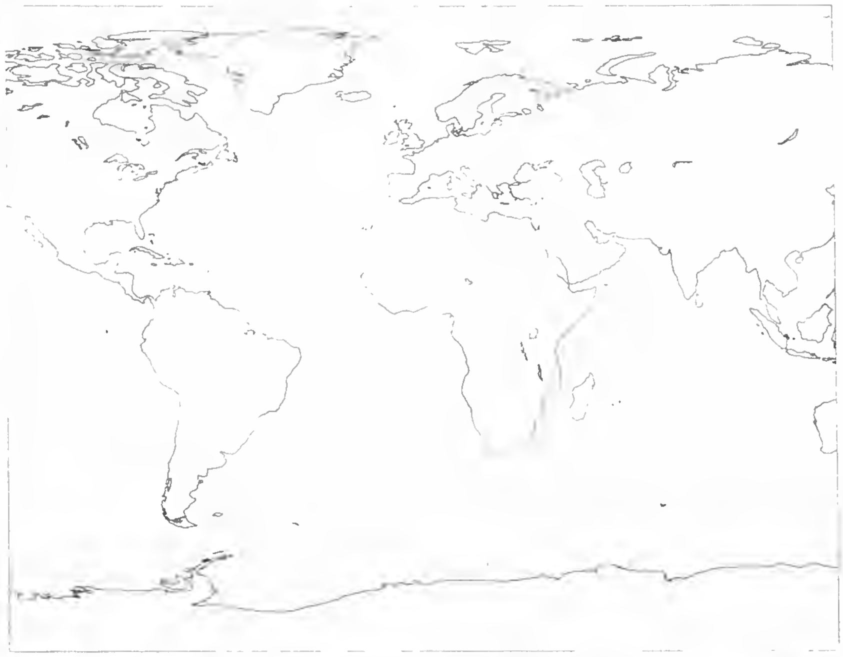


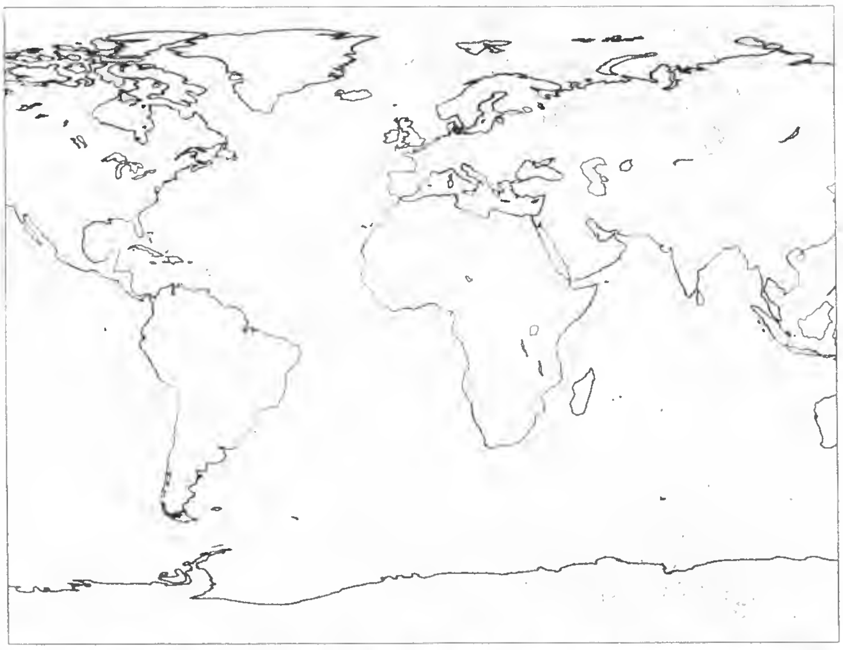
Figure 3. Artist's impression of the GOME instrument's scanning geometry

movement of the instrument's scanning mirror. this instantaneous field of view can be scanned across the satellite's track. With a ±31° scan, global coverage can be achieved within 3 days, except for a gap of approximately 4° around both poles. To overcome this limitation, a special pole-viewing mode has been included (Figs. 3 & 4a,b)

The GOME instrument is mounted externally, on the surface of the payload module facing in the flight direction (i.e. the –Y face), with a clear field of view in the nadir direction (Fig. 5) It is thermally decoupled from the spacecraft structure as far as possible

Photon flux computations show that for the visible/near-infrared channels, a good signal-to-noise ratio can be achieved with a 1.5 s integration time on the detector. The time for one forward scan has therefore been set to 4.5 s. For the flyback of the scanning mirror, another 1.5 s have been allowed, resulting in the scan pattern shown in Figure 6, with a ground pixel size of 320 km x 40 km.





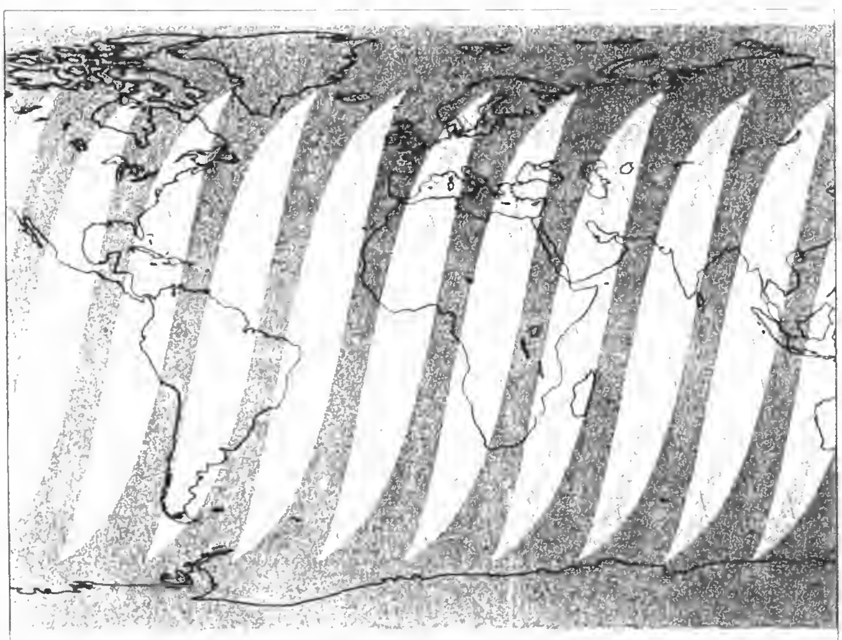
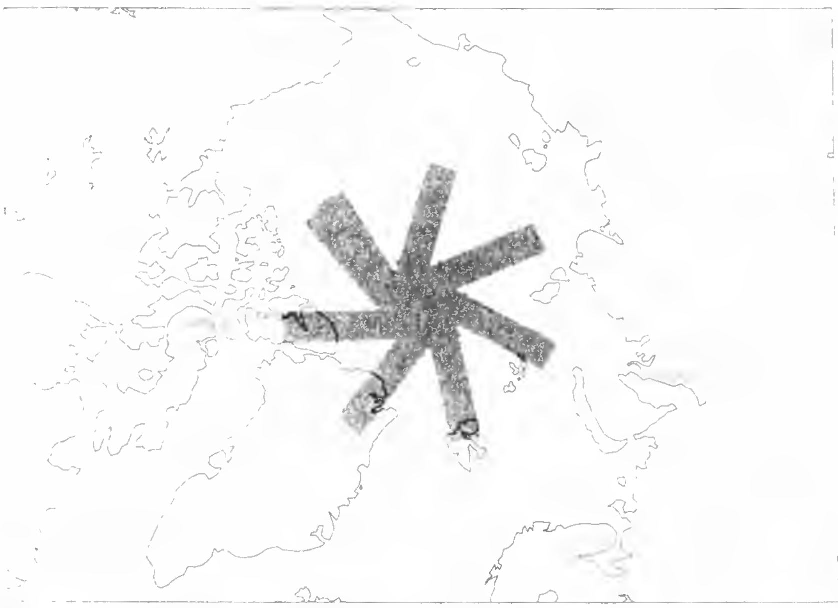


Figure 4a. Three-day coverage map for GOME



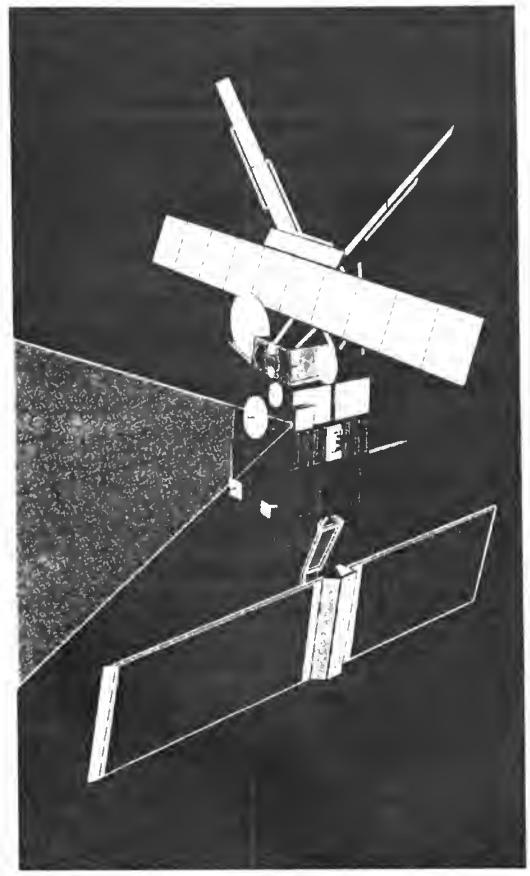


Figure 5. Artist's impression of the GOME instrument aboard ERS-2

The instrument's design

As a general principle, the GOME instrument collects light arriving from the Sun-illuminated Earth's atmosphere and decomposes it into its spectral components. In order to provide both the required spectral coverage from 240 to 790 nm and a good spectral resolution of 0.2–0.4 nm, this decomposition is done in two steps: first by a quartz pre-disperser prism, in which the light is split into four different channels. Each of these channels contains a grating as second dispersing element, and a 1024-pixel silicon array detector (the integration times on the chip can be multiples of 93.75 ms, with 1.5 s for the visible and 30 s for the ultraviolet being the default values).

The entire GOME instrument can be broken down into the following functional blocks:
- the spectrometer
- the four Focal-Plane Assemblies (FPAs)
- the Calibration Unit
- the scan unit with the scanning mechanism and the scan unit electronics (SEU) assembly

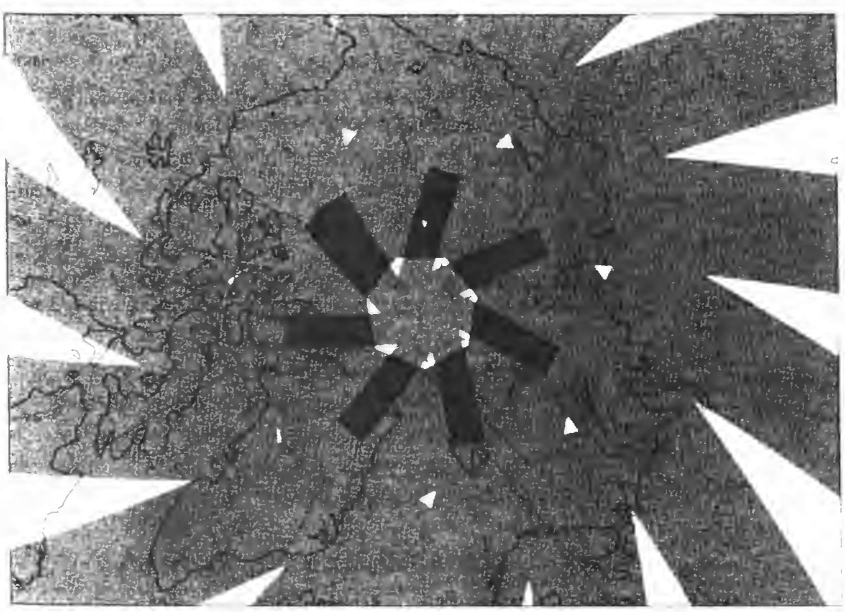


Figure 4b. Three-day coverage map for GOME

- the Polarisation Measurement Device (PMD)
- the Digital Data Handling Unit (DDHU)
- the optical bench structure
- the thermal control hardware.

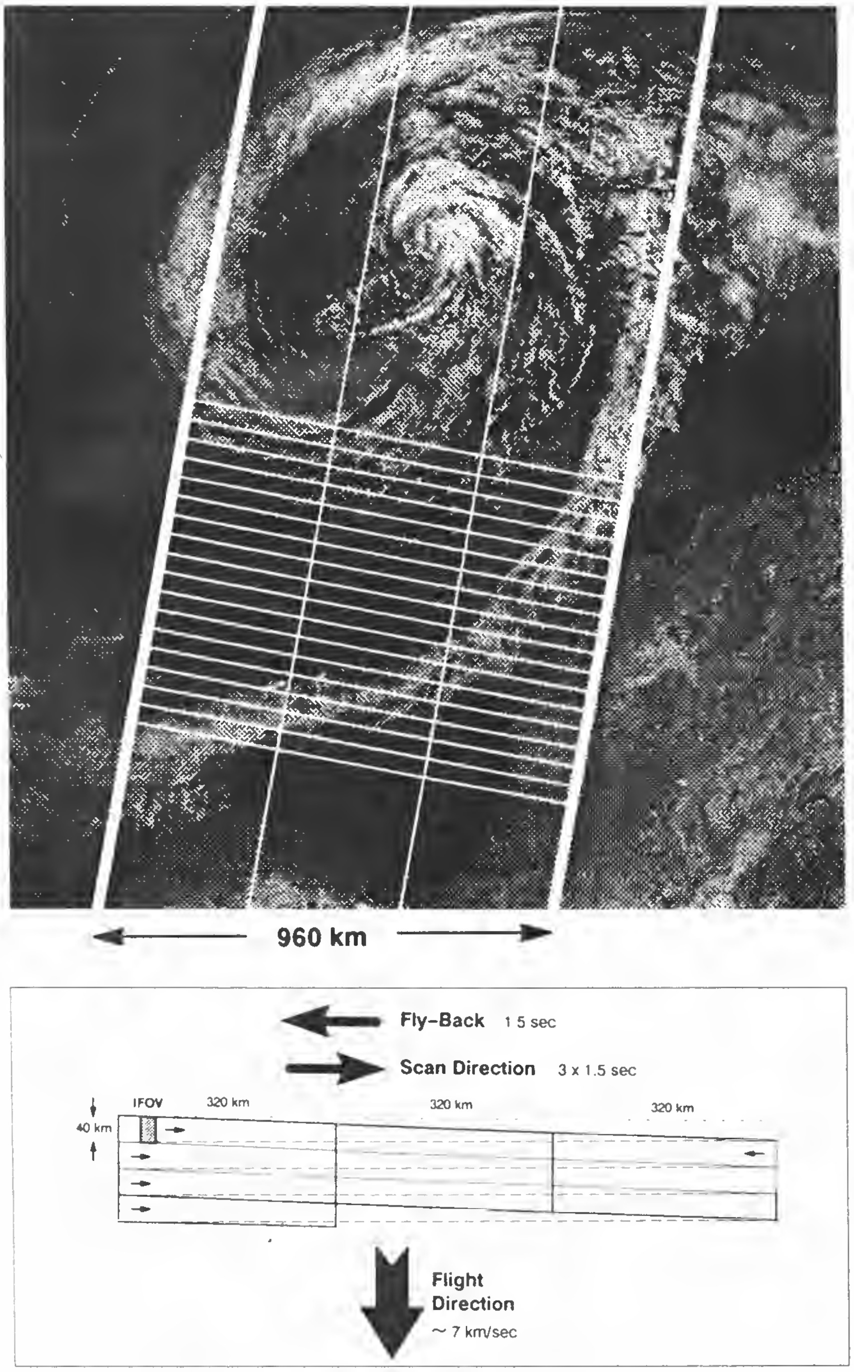


Figure 6. GOME scan pattern (graphic courtesy of DLR, Oberpfaffenhofen)

Table 1. Key optics performance parameters

Band	Wavelength range (nm)	Grating (l/mm)	Pixel resolution (nm)	Spectral resolution (nm)
1A	240–268	3600	0 11	0 22
1B	268–295			
2A	290–312	2400	0 12	0 24
2B	312–405			
3	400–605	1200	0 2	0 4
4	590–790	1200	0 2	0 4

Spectrometer optics

In the spectrometer optics, shown schematically in Figure 7, the light reflected off the scanning mirror is focussed by an anamorphic telescope such that the shape of the focus matches the entrance slit of the spectrometer (dimensions 10 mm x 100 µm. After the slit, the light is collimated by an off-axis parabolic mirror. It then strikes the quartz pre-disperser prism, causing a moderately wavelength dispersed beam. Another prism acts as channel separator. the upper edge of this prism reaches into the wavelength-dispersed beam, letting the longer wavelengths pass, reflecting the wavelength range 290–405 nm into Channel 2 by means of a dielectric reflecting coating, and guiding the wavelength range 240–295 nm internal to the prism into Channel 1. The unaffected wavelength range of 405–790 nm is then split up by a dichroic beam splitter into Channels 3 (400–605 nm) and 4 (590–790 nm)

Each individual channel consists of an off-axis parabola, a grating, and an objective with f-numbers of 2 (Channels 1 and 2) and 3 (Channels 3 and 4), finally focussing the light onto the detectors contained in their respective Focal-Plane Assemblies

The most critical optical elements in the optical chain are the diffraction gratings, which have to provide both a high efficiency in the first diffraction order and a very low level of stray light and ghosting. Because of the criticality of the gratings for the final performance of the instrument, two parallel development programmes are under way, at the firms of Jobin-Yvon in France and Carl Zeiss in Germany. Some of the key performance requirements for the optics are summarised in Table 1.

Focal-Plane Assemblies

The FPAs are made from titanium and have a sealed quartz window at the side where they are flanged to the respective objective tubes. The rear side of the FPA, the so-called 'pin-plate', is a titanium plate provided with electrically isolated, vacuum-tight feed-throughs for the electrical connections to the detector. This is a Reticon RL 1024 SR random-access diode array detector with 1024 pixels, each pixel measuring 25 µm in the dispersion direction and 2.5 mm in the along-slit direction. Each diode is randomly accessible by an address bus and can be read out individually

In the GOME instrument, the detectors of Channels 1 and 2 are split into several

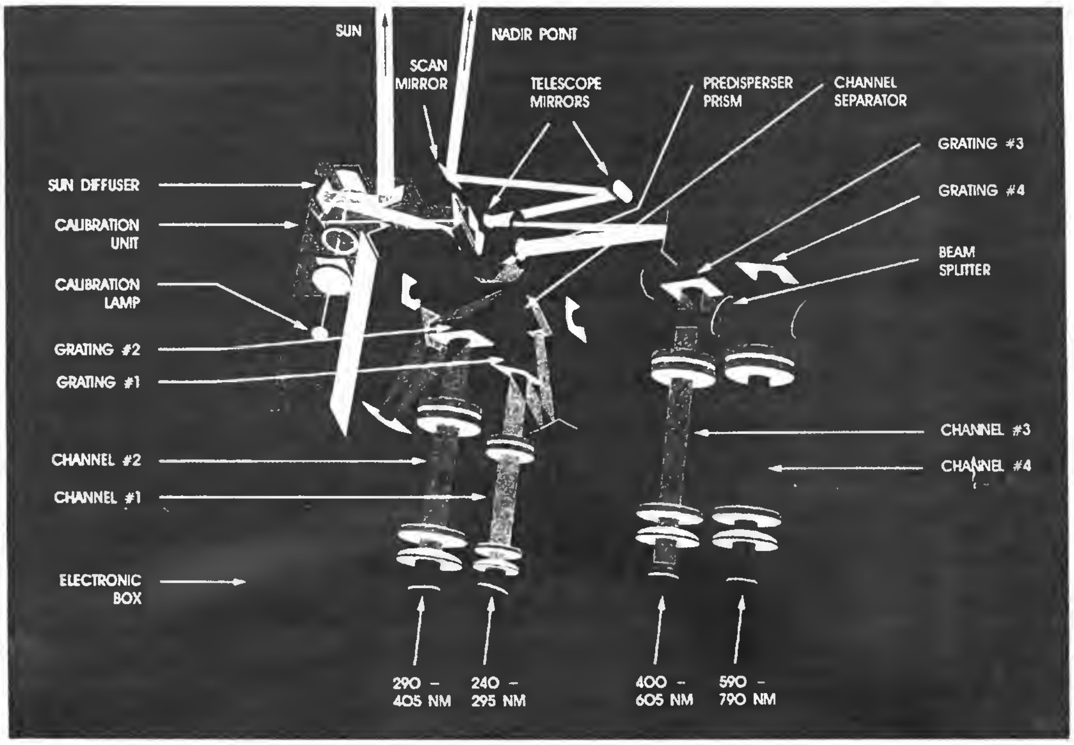


Figure 7. Spectrometer optics

bands, the integration times of which may be varied individually. The Reticon detector chip is shown in Figure 8. The detectors are glued onto two-stage Peltier coolers, which reduce their temperature to −40°C to keep the dark current of the photodiodes sufficiently low. The hot side of the Peltier coolers is glued (in the engineering model), respectively brazed (in the flight model), to a copper bar, extending through the pin-plate. Outside the FPA, this copper bar is connected via flexible connections and heat pipes to the main radiator. The tips carrying the Peltier coolers and detectors are tilted between 1.6° and 9.5° to compensate for chromatic aberration.

At the back side of the FPA, the Front-End Electronics (FEE) are mounted on a printed-circuit board. They are based on a charge amplifier implemented with a low-noise amplifier and a dual-FET input stage. The output of the FEE is fed to the Digital Data Handling Unit (DDHU), where it is further processed and digitised.

During ground operations, the FPAs can be either evacuated, or filled with dry nitrogen to avoid moisture freezing out on the cooled detectors. In addition, the polarity of the Peltier elements can be inverted to heat the detectors to +80° to drive off possible contaminants and to anneal radiation effects. Once in orbit, the FPAs are exposed to the vacuum of space by a burst membrane, which is designed to open during the launch phase.

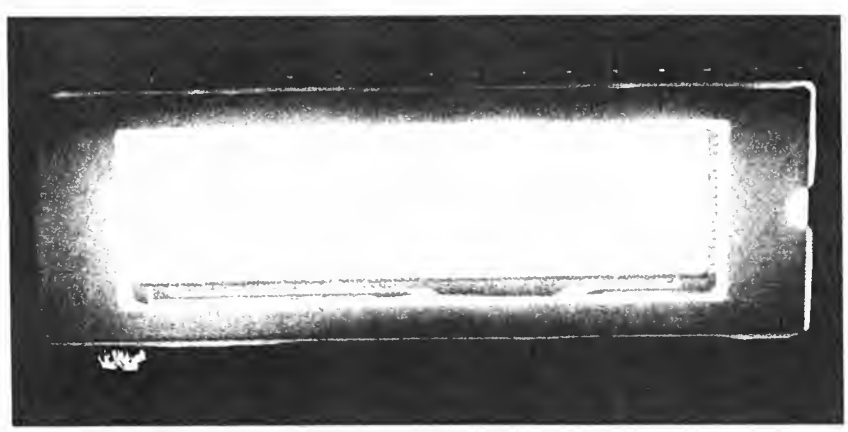
Calibration unit

In order to support the DOAS technique, one would like to have a wavelength stability of 1/100 th of a pixel. This is not achievable with a passive thermal design in such a power-limited situation. Instead, wavelength position on the detector pixels versus orbital temperature will be mapped by means of a hollow-cathode lamp (Pt-Cr-Ne) which provides a sufficient number of sharp lines in all wavelength regions.

For the radiometric calibration, the Sun will be used as the source. Because of the orbital and scanner geometry, which prevents direct viewing of the Sun via the scanning mirror, and because its high intensity would lead (even with the shortest possible integration time) to detector saturation, the Sun is viewed via a diffuser plate accommodated in the calibration unit (Fig. 9).

Previous NASA experience has shown that the diffuser is subject to degradation during its periods of exposure. Precautions are therefore taken by having:

Figure 8. Reticon RL1024SR detector chip



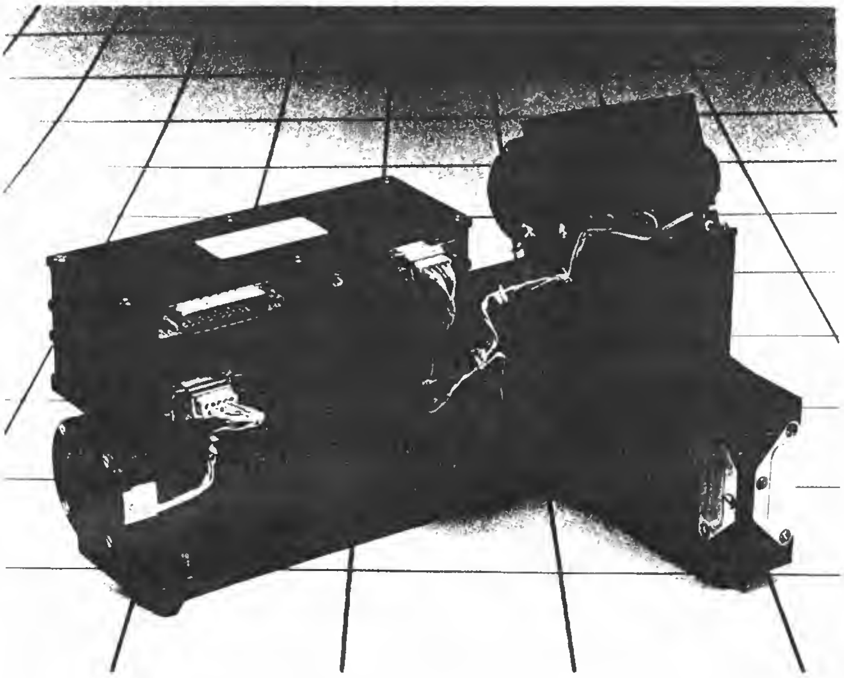


Figure 9. Calibration unit

- a mesh in front of the diffuser, attenuating the incoming light level and largely protecting the diffuser
- a shutter mechanism that opens only during Sun calibration and protects the diffuser during the remaining mission phases
- the possibility to view the calibration lamp via the diffuser, thereby having a means to monitor possible degradation, at least at those wavelengths provided by the lamp.

Scanning unit

The scanning unit consists of two separate assemblies, the Scan Mechanism (SM) and the Scan Unit Electronics Assembly (SUEA). The scan mechanism is located on the optical bench, with its rotation axis aligned with the satellite's flight direction. The axis carries a glued-on aluminium-coated mirror, which can be heated from the rear to drive off possible contaminants, if necessary.

A brushless DC motor actuates the scanner, the position of which is sensed by a resolver. The rotating part of the resolver, the mirror heater and the temperature sensor are connected to the static part via a flexible printed-circuit connection. The angular range of the scanner is limited to −63.8 to +192.2° with respect to nadir (0°) by software and end stops.

The rotation axis is supported by two spring-preloaded angular contact bearings, the balls of which are ion-plated with lead and the races are made of lead bronze. All structural parts (housing, pivot, etc.) are made from titanium.

Polarisation measurement device

The incoming light from the Earth's atmosphere can be partially polarised. Because the instrument's responses to the two orthogonal linear polarisation directions are not equal, there is a need to monitor the polarisation of the incoming light.

In the pre-disperser prism, light is internally reflected at the Brewster angle. About 5 % of this light, polarised normal to the plane of incidence, leaks away at this surface. This light is collected by an off-axis parabola, reflected by a mirror out of the plane of the optical bench, and then sensed by a custom-made photodiode array.

Because the device is not temperature-controlled, it is subject to drifts. To keep the impact of changing temperatures to a minimum, a second array of photodiodes with the same geometry, but not exposed to light, will be used to compensate for the dark current and its variability with temperature.

The measured signals are acquired by the DDHU, converted to digital signals, and included into the telemetry data (3 x 16 bit, 10.67 Hz)

Digital Data-Handling Electronics (DDHU)

The prime interface to the satellite's electrical subsystems is via the Digital Electronics Unit (DEU) of the Along-Track Scanning Radiometer (ATSR). Because the DEU now not only controls the ATSR's Infrared Radiometer (IRR) and Microwave Radiometer (MWR), but also GOME, a redundant DEU has been added, together with a DEU Switching Unit (DSU).

The DEU assumes all the normal functions of an Instrument Control Unit (ICU). Commands dedicated to GOME are expanded into a serial digital bit stream, initiating the appropriate actions within the DDHU. In the opposite direction, both housekeeping and scientific data are written by the DDHU into data buffers, from which they are requested by the DEU to be put into predefined fields of the ATSR S-band and X-band data streams.

Thermal-control hardware

The most critical aspect of the thermal control is the detector temperature, which is provided by the Peltier elements in each of the Focal-Plane Assemblies. The hot sides of the Peltiers are all connected, via copper bars and flexible connections, to a parallel pair of bent heat pipes, which end in the primary radiator exposed to deep space.

The DDHU and the scanning mirror electronics assembly have their own radiative surfaces for thermal control. The remainder of the instrument is wrapped in multi-layer insulation blankets. For cold non-operational phases, thermostat-controlled heater mats and resistors are directly powered from the payload's Power Distribution Unit.

Structure

All elements of the optics, mechanisms, electronics and thermal hardware are mounted on the optical bench, which is a nearly rectangular aluminium plate with stiffening ribs beneath. This optical bench is carried on four feet, one of which is round in cross-section and rather stiff. The other three are blade-shaped feet, with their flexing direction lying in the direction of the fixed foot. This prevents mechanical distortion of the optical alignment due to thermal expansion of the bench.

Beneath the optical bench, in the space between the ribs, the harness and the pipework for FPA evacuation are routed. An EMC shield protects the instrument from electromagnetic interference from the satellite's radars and communications system.

Operations

The GOME instrument has numerous measurement, calibration, and support modes. In particular, due to the varying light levels that will be experienced during each orbit, integration time settings will have to be adjusted frequently. In addition, once per day a Sun calibration has to be performed.

In order to limit the command traffic on the uplink, the DEU stores three different timelines, each of which can be activated automatically up to 16 times in sequence. One of these timelines is for normal operations, one for an orbit in which a Sun calibration is being performed, and one with a sidewards swath to cover the polar area (with the normal nadir-centred swath there would be a gap in coverage of about 4° around both poles).

About once per month, a wavelength mapping as function of the thermal variations will be performed with the wavelength calibration lamp. On these occasions a diffuser characterisation can also be carried out.

Lunar observations, which are restricted by the Sun–Moon–satellite scanner field-of-view geometry, will be performed whenever possible.

Data processing

GOME data will arrive together with the other 'low-bit-rate' data at the various ground stations to which the ERS tape recorders are downlinked. Extracted GOME data, together with orbit and attitude information, will then be shipped on Exabyte cassettes to the German Processing and Archiving Facility (D-PAF) in Oberpfaffenhofen. In a first processing step, the raw data will be corrected for instrument-induced errors and drifts, and provided with information on geo-location, Sun aspect angle, etc.

From these radiometrically and wavelength corrected geo-located spectra, the ozone total column amount, ozone vertical concentration profile, and data on aerosol loading and cloud cover can be retrieved. This will be done at distributed centres, according to the particular scientific expertise available. Time and budgets permitting, other atmospheric-constituent retrieval can be added to the range of data products generated. Finally, time and spatial averaging for long-term global-trend analyses is likely to be conducted (not yet specifically defined).

In addition to this off-line processing chain, some limited processing capabilities will also be installed at ESTEC, in order to evaluate the instrument performance after launch, optimise parameter settings and operating schemes, and to support possible scientific campaigns.

GOME should produce unique data as there will be no other instrument available on its time scale which duplicates its capabilities. The instrument fills a critical slot as far as future observing strategies are concerned, and GOME could well become the prototype for subsequent ozone-monitoring instruments. Its medium spectral resolution combined with a wide spectral range and absolute calibration is particularly important as it means that, in addition to applying the traditional backscatter approach, one can also use differential optical absorption spectroscopy to retrieve data with GOME.

Acknowledgements

We gratefully acknowledge the unfailing support of the GOME Science Team, headed by Prof. Dr. J. Burrows from the University of Bremen (D). Much of the work reported here has been done by the GOME Industrial Team, comprised of Officine Galileo (I), Laben (I), TPD/TNO (NL), Dornier (D) and the Rutherford Appleton Laboratory (UK), and BAe (UK) for the DEU modifications.

Envisat and the Polar Platform: The Concept and Its History

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Following the decisions taken at the ESA Council at Ministerial Level in Granada last November, use of the European Polar Platform as the basis for the Envisat Programme has been confirmed. A well-balanced set of instruments has now been selected to make up the payload complement for Envisat-1 and a nominal Industrial Consortium arrived at for its development. This article briefy traces the history of the Programme and outlines the current mission concept and the proposed industrial organisation for its implementation.

Introduction

The issue of how man interacts with the environment and, in more general terms, the ecological consequences of all human activities started to be a matter of increasing public interest in the late 1960s. In recent years, it has become one of the major topics of discussion in everyday life. The 'greenhouse effect', acid rain, the hole in the ozone layer and the systematic destruction of the tropical rain forests are all now the subjects of passionate debate.

This new awareness of the environmental and climatic changes that may be overtaking our entire planet has provided support for a growing scientific interest in the complex interactions that occur between the Earth's atmosphere, oceans, ice regions and land surfaces. This scientific interest has created, over the years, a well-established community of scientists active in these disciplines.

At the same time, the global perspective of the Earth's environment has fostered the development of a number of space-based remote-sensing techniques for earth observation. Starting with its ERS-1 Programme, ESA has played a key role in the development of these techniques for a wide range of applications. In 1988, all of these elements were drawn together in an ESA proposal to its Member States for an overall 'Strategy for Earth Observation'. A series of polar-orbiting and geostationary satellites was foreseen, to support several missions covering, in particular, the study of the Earth's environment and resources, the continuation and improvement of meteorological observations, and the study of the structure and dynamics of the Earth's crust and interior.

Based on the scenario defined in that ESA strategy for Earth-Observation Programmes, the first Polar Orbit Earth Observation Mission (POEM-1) was established as an optional Agency Programme, via a Resolution of the ESA Council Meeting at Ministerial Level in Munich in November 1991. The exact content of the POEM-1 Programme was subsequently elaborated in a further Resolution, adopted at the next ESA Council Meeting at Ministerial Level, in Granada in November 1992. On this occasion, the two constituent elements of the Programme were further defined as the Envisat-1 mission and the Metop-1 mission preparatory programme.

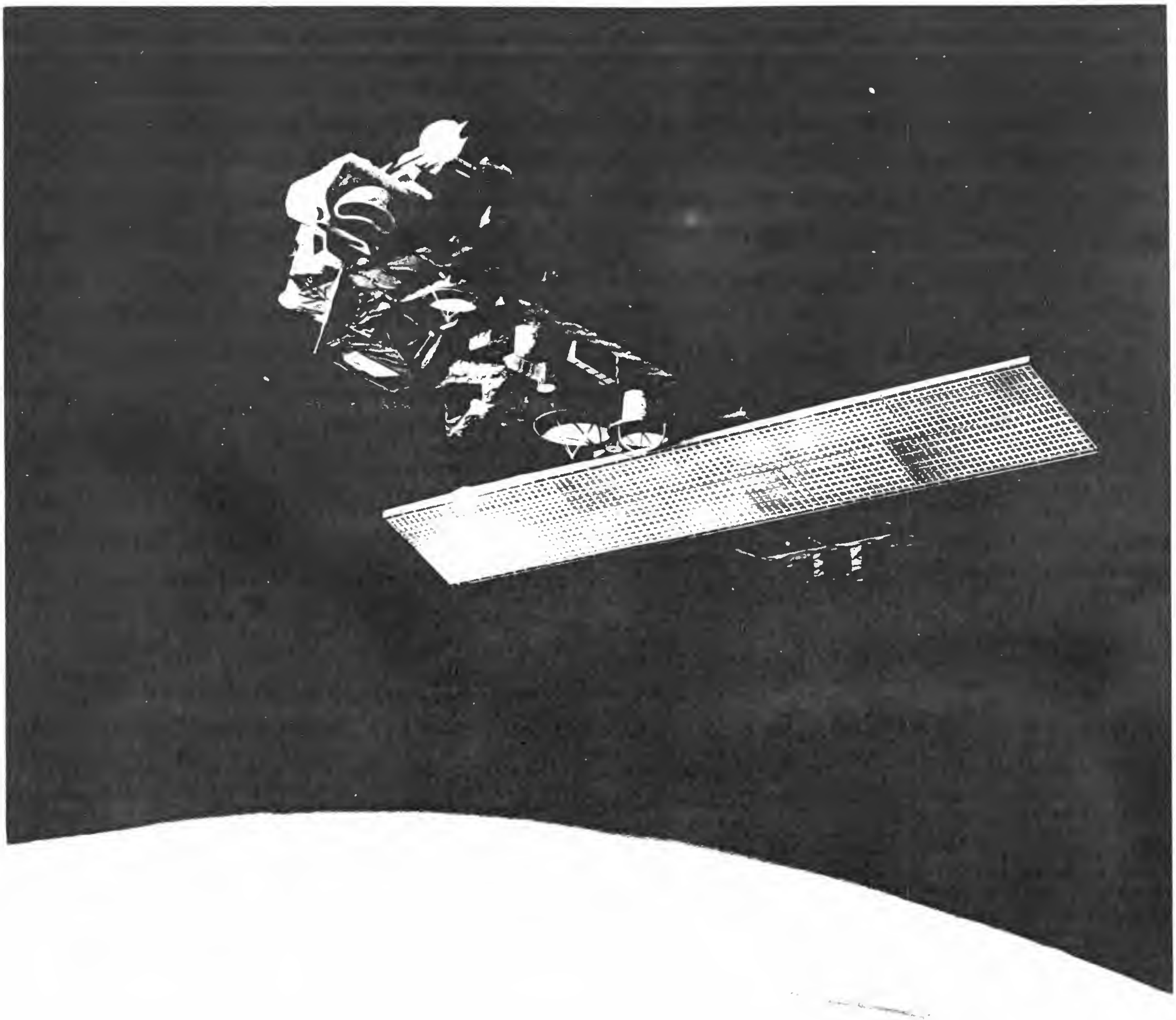
With its launch foreseen for late 1998, Envisat-1 will be the first earth-observation mission based on exploitation of the European Polar Platform. It is primarily a research-oriented mission and will carry essentially pre-operational instruments for monitoring and studying the Earth's environment, including climate changes. The later Metop-1 mission will be more oriented to routine operational observations and climate monitoring.

Major mission elements

The two major elements of the Envisat-1 mission are:
- the space segment, consisting of the Envisat-1 Payload Instruments on the Polar Platform (PPF), and
- the ground segment, composed of the Flight Operations Segment and the Payload Data Segment.

The space segment

The overall configuration of Envisat-1 (Fig. 1)



is driven by the instruments' observation and accommodation needs, the Polar Platform's general layout and the need to be compatible with the Ariane-5 fairing.

The configuration of the Payload Module has been the object of intense and careful optimisation in order to accommodate all the instruments physically and provide them with the requisite fields of view, whilst still respecting a number of inherent constraints in terms of necessary clearances, etc. In particular, a detailed trade-off was performed between a three-sections versus a four-section PPF Payload Module (PLM). It was concluded that, for the chosen Envisat-1 payload complement, a three-section PLM did not offer sufficient accommodation space or surface-mounting area. The final configuration of the four-section Payload Module and the locations of the various instruments are shown in Figure 2.

Most of the instruments are mounted on the outside of the PLM, while the electronics units for the ASAR, RA and GOMOS instruments have been accommodated, together with the PPF electronics, inside the Payload Equipment Bay (PEB). The instruments themselves are described in detail in the companion articles in this issue of Bulletin. It should perhaps be recalled here, however, that the selected payload complement consists of a group of ESA Developed Instruments (EDIs), funded under the Envisat-1 Programme, and a group of Announcement of Opportunity (AO) Instruments, funded nationally by the Participating States:

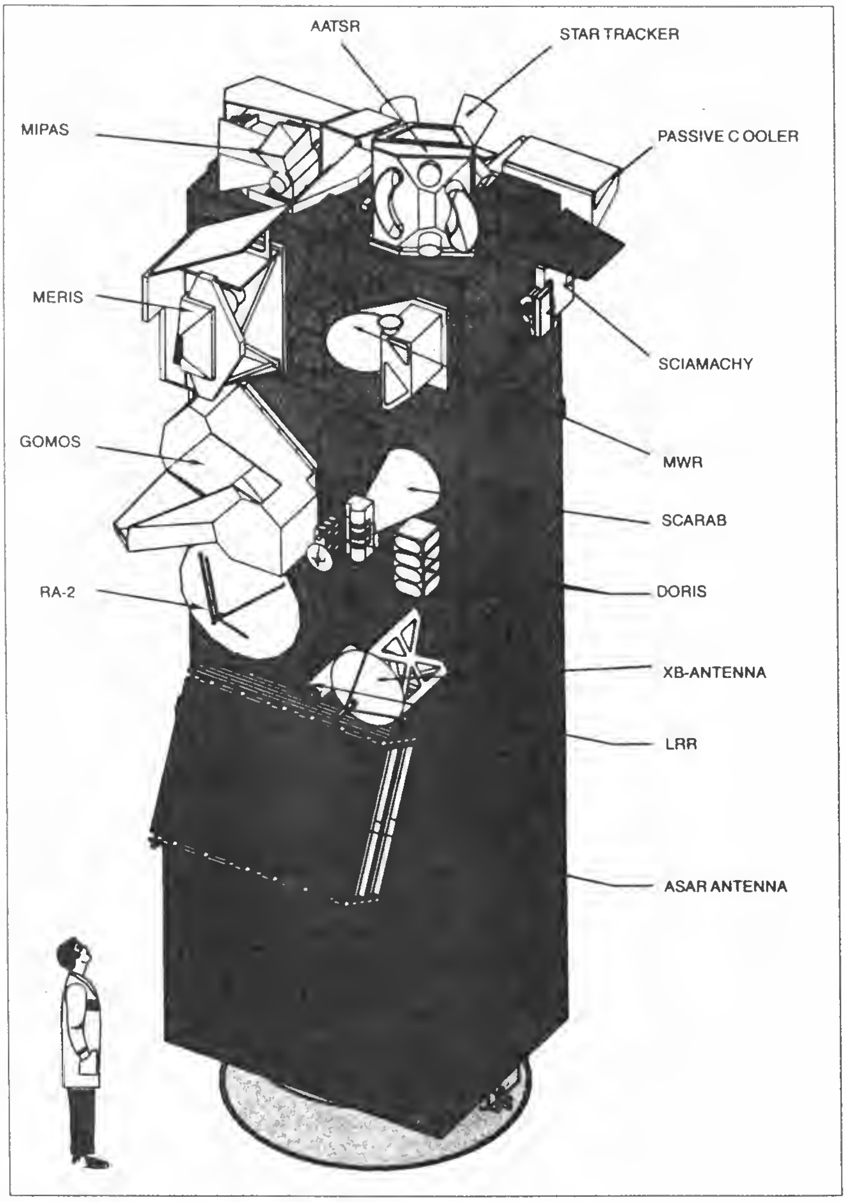
EDI instruments
- Medium-Resolution Imaging Spectrometer (MERIS)
- Michelson Interferometric Passive Atmospheric Sounder (MIPAS)

Figure 1. Artist's impression of Envisat-1

- Advanced Radar Altimeter (RA-2), including a Microwave Sounder
- Advanced Synthetic Aperture Radar (ASAR) capable of operating in both imaging and wave modes
- Global Ozone Monitoring by Occultation of Stars (GOMOS)
- Microwave Radiometer (MWR).

AO instruments
- Scanning Imaging Absorption Spectrometer for Atmospheric Cartography (SCIAMACHY), provided by Germany and The Netherlands
- Advanced Along-Track Scanning Radiometer (AATSR), provided by the United Kingdom
- Scanner for Radiation Budget (SCARAB), provided by France
- Doppler Orbitography and Radio-positioning Integrated by Satellite (DORIS), provided by France.

Figure 2. The Envisat-1 payload



The main design and development Phase (Phase-C/D) for the ESA-developed instruments was started in July 1992. Detailed design activities were initiated first at the level of the mission and instrument prime contractors, whilst the complete make-up of the Envisat-1 Industrial Consortium was being finalised. As this has now essentially been decided, work can proceed in all areas.

The next important milestone is the satellite and mission-level Preliminary Design Review (PDR) in Spring 1994. Preparations for this are already well underway, including PDRs for the entire PPF and some of the instruments.

In its role of Mission Prime Contractor, Dornier GmbH (D) is leading the Consortium of more than 50 European and Canadian companies. The Instrument Prime Contractors for the EDI instruments are:
- Aerospatiale (F) for MERIS
- Alenia Spazio (I) for RA-2
- DASA (D) for MIPAS
- MMS-F (F) for GOMOS
- MMS-UK (UK) for ASAR/MWR.

An overall schedule for the Envisat-1 mission elements is shown in Figure 3.

The Polar Platform

The Polar Platform Programme was started in the framework of the Columbus Programme back in 1987. After several iterations of the Platform concept (serviceable or not) and its basic characteristics (payload mass and power capabilities), it was decided at the end of 1989 to start the development of a multi-mission Polar Platform offering a modular range of capabilities to the payload. (The multi-mission Polar Platform was extensively described in ESA Bulletin No. 71, in August 1992).

Following the decisions taken in November 1992 at the Granada Ministerial Conference to split the POEM-1 Mission (for which the PPF, at its upper range of capabilities, was particularly well-suited) into the Envisat-1 and Metop-1 series of missions, the Polar Platform Programme has been reoriented to support these programmes, concentrating initially on the Envisat-1 mission. To this end, the design modularity existing in the multi-mission PPF has been used to tailor it to the specific Envisat-1 mission needs.

The Polar Platform is comprised of two major modules (Fig. 4):
- The Service Module, the design of which is largely derived from Spot-4, provides

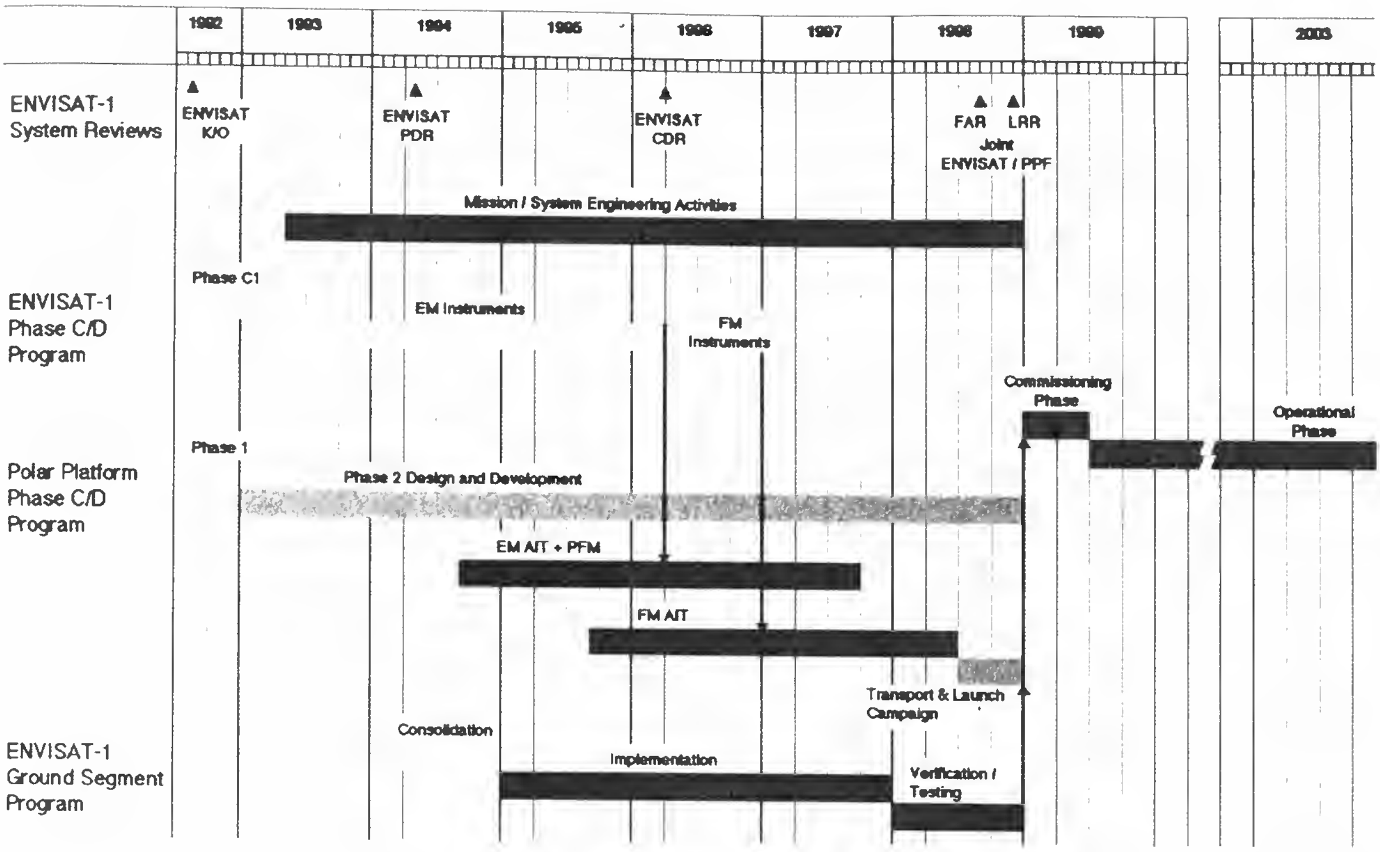


Figure 3. Envisat-1 mission summary barchart

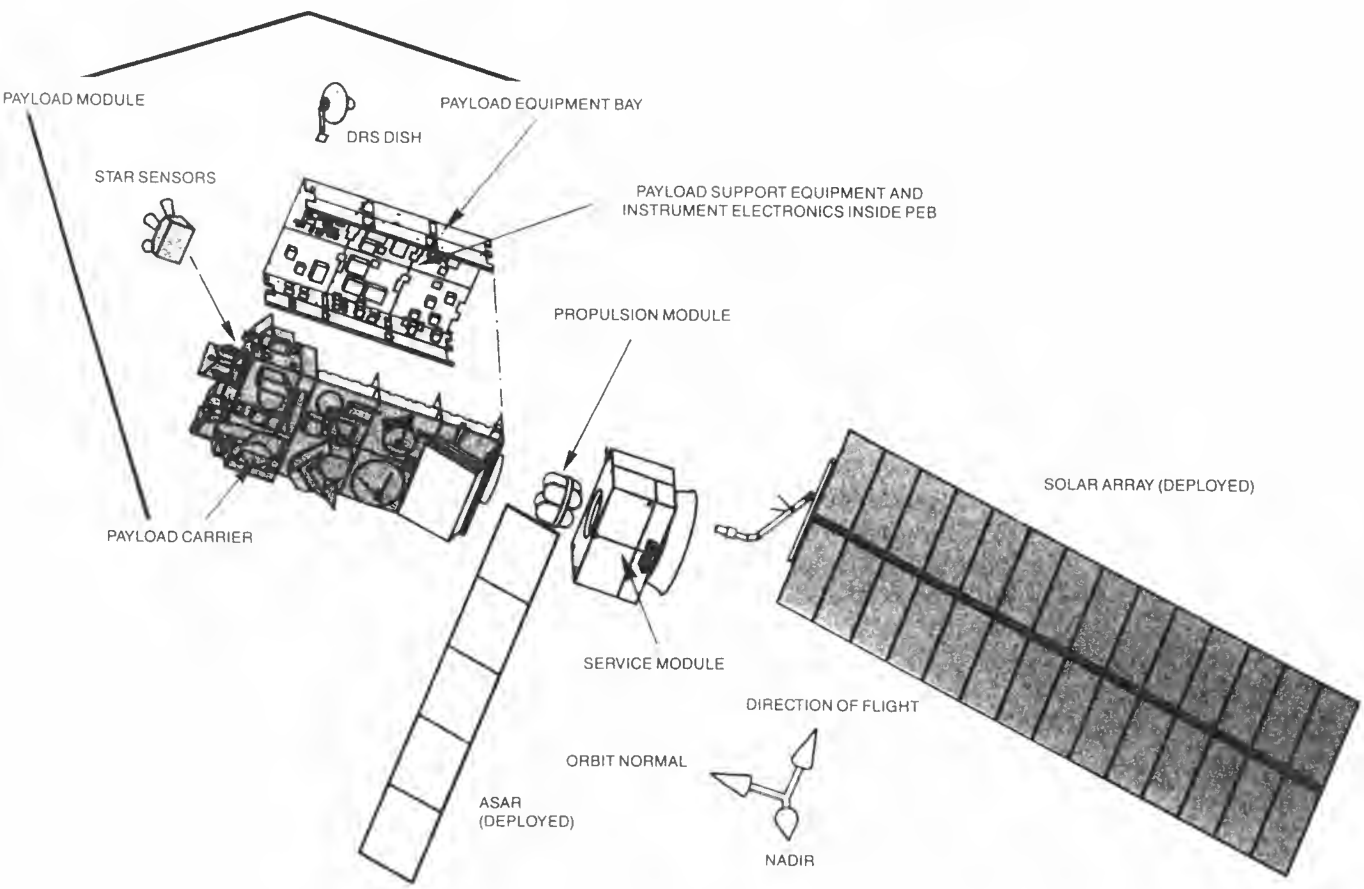


Figure 4. Envisat-1/ Polar Platform functional breakdown

the main satellite support functions, such as power, attitude and orbit control, and propulsion. It also interfaces with the launcher.
- The Payload Module, on which the Envisat instruments and PPF payload support equipment (data management and communications, electrical distribution) are accommodated.

Table 1. Polar Platform services to the payload

Mounting surface	Up to 43 m^2 externally (PLC), and 10 m^2 inside (PEB)
Mass	Up to 2000 kg of payload instruments
Power	1.9 kW average over the orbit, 2.5 kW peak power
Data handling	o One high-rate channel for ASAR (100 Mbps) o Ten medium-/low-rate (up to 32 Mbps) channels for the other instruments o Recording at 5 Mbps on up to 4 tape recorders with replay at 50 Mbps. Maximum capacity (30 Gbits) for storage of one full orbit of medium-/low-rate data
Data transmission	o Real-time high-rate together with recorded or real-time low-/medium-rate data can be down-linked simultaneously in X-band direct to ground or in Ka-band via DRS o Two (out of three) channels are provided for both Ka- and X-band, each 50/100 Mbps
Attitude	o Star-tracker-based reference system o Pointing better than 0.1° (3 σ) o Measurement better than 0.03° (3 σ)

The Payload Module in turn has two functional subassemblies in addition to the Payload Instruments proper:
- The Payload Carrier (PLC), which is the structure and harness supporting the externally mounted instruments and some PPF equipment (Ka-band antenna and star trackers). The structure is composed of four similar sections, each 1.6 m in length (five were foreseen for the multi-mission Platform).
- The Payload Equipment Bay (PEB), constituted by the equipment (belonging to either platform or instruments) mounted internally on the nadir and side panels of the three lower sections of the Payload Module.

The Service Module combines a newly designed structure, thermal control and solar array with Spot-4 recurrent or partly modified hardware for the electronic equipment (AOCS, OBDH, power) and for the propulsion subsystem. It also carries a newly designed Dual-Mode Transponder (DMT), which will provide S-band communications for commanding either direct from the ground or via a Data-Relay Satellite.

The Solar Generator is made up of 14 panels (multi-mission was 16), measures 14 m x 5 m, and provides 6.5 kW of power at end-of-life.

The services offered by the Polar Platform to the payload for the Envisat-1 mission are summarised in Table 1.

Development status

The Polar Platform has now been under development for more than three years, based on the Phase-C/D Proposal received from Industry in October 1990. Since then, the detailed design work has been basically completed and the majority of the development models successfully manufactured and tested (see, for example, Fig. 5). The updates to the design resulting from the reorientation to meet the needs of the Envisat-1 mission have also been introduced.

Manufacture of the PPF structural model is currently well-advanced with the Service Module completed and due to enter static qualification testing this autumn.

A Preliminary Design Review (PDR) has been performed by the Agency in November 1992 for the multi-mission Polar Platform.

The ground segment

Extensive ground facilities are required to support the Envisat-1 mission, both to command and control the satellite and to handle the very large quantities of data that will be provided by the instruments on-board. Specific efforts will be made in both of these areas, taking into account the existing ESA ground infrastructure and capitalising on the experience gained and lesson learnt from the ongoing programmes, and from ERS-1 in particular.

The command and control of the satellite is to be organised by the European Space Operations Centre (ESOC) in Darmstadt (D) using Kiruna (S) as the primary S-band station, complemented by commanding via DRS.

The handling of the payload data is to be organised by ESRIN, with both X-band and DRS reception facilities being used. Processing of data within the Envisat-1 Ground Segment itself will be limited, with only engineering data, calibrated by instrument, being provided in most cases.

Clearly, the end users of the Envisat-1 data will need data that have been further processed to provide a range of geophysica data products. Intensive discussions are

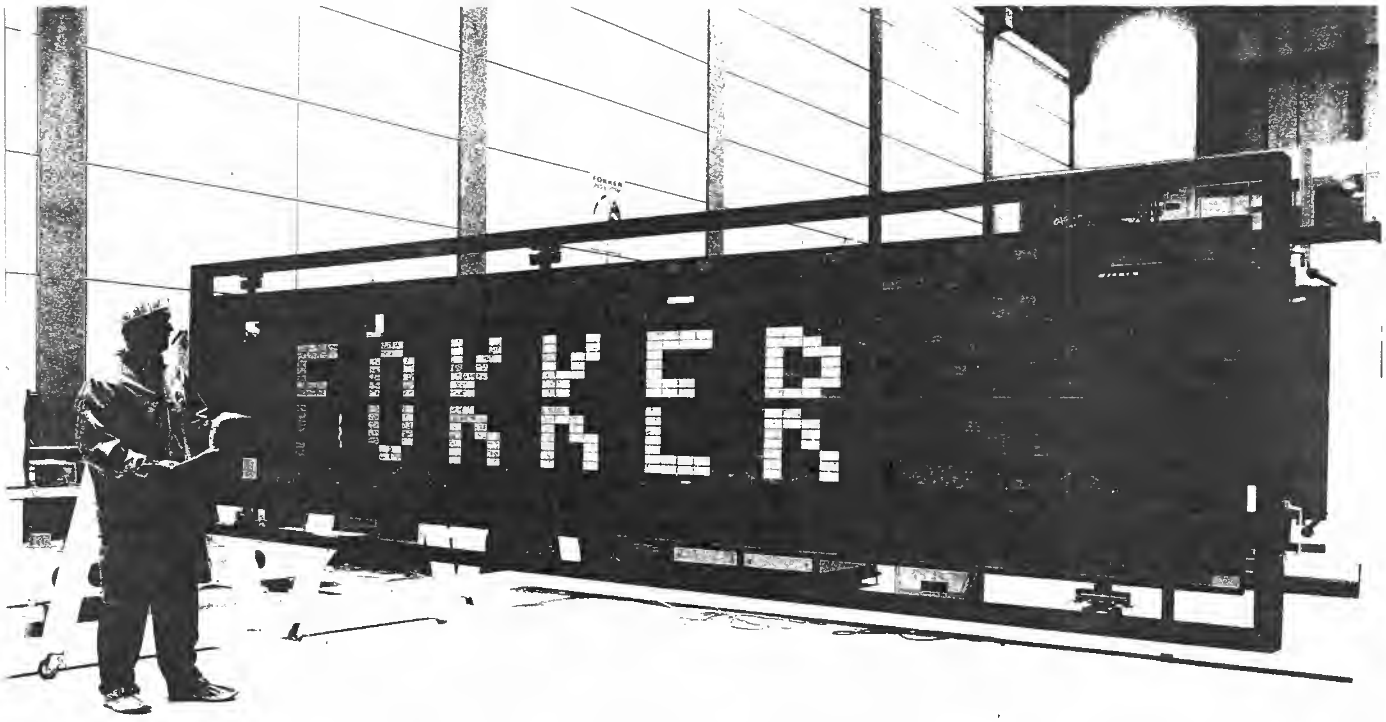


Figure 5. A Polar Platform solar-array panel under test

currently taking place within the European User Community to determine the best way to ensure that such geophysical products can be made easily available to the widest possible community.

The solution eventually implemented will make use of facilities owned and operated by ESA's Member States, facilities to be implemented as part of the Agency's Data User Programme, and possibly also facilities owned and operated by the European Community.

The overall infrastructure will be supported by a wide circle of scientific endeavours in order to optimise the overall data processing and obtain the maximum amount of useful information from Envisat-1's instruments.

Conclusion

For the Earth-Observation User Community, the Envisat-1 mission will provide invaluable data for a broad field of applications, leading to a better understanding of the Earth's environment, its climate and the ecological consequences of human activities on a global scale.

The mission represents a major challenge for ESA in that it combines the efforts of two of its major programmes, namely the Envisat-1 and PPF Programmes. The overall system is complex, from both the technical and organisational points of view, with a large number of interfaces and very ambitious goals. It is also, therefore, a challenging task for the companies that make up the Polar Platform and Envisat-1 Industrial Consortia.

GOME: A New Instrument for ERS-2

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The Global Ozone Monitoring Experiment, or GOME, is a new instrument that will be added to the original ERS-1 payload complement for the launch of the second European Remote-Sensing Satellite (ERS-2) in 1994. GOME is a nadir-viewing spectrometer which will observe solar radiation transmitted through or scattered from the Earth's atmosphere or from its surface. The recorded spectra will be used to derive a detailed picture of the atmosphere's content of ozone, nitrogen dioxide, water vapour, oxygen/oxygen dimer and bromine oxide and other trace gases. ERS-2's orbit will provide global Earth coverage every three days.

Introduction

In 1989, ESA decided to continue the ERS Programme beyond the expected lifetime of the ERS-1 satellite by approving the building and launch of the ERS-2 satellite. To provide the necessary continuity to the observations started by the instruments of ERS-1, ERS-2 is essentially a carbon-copy of the ERS-1 satellite. It was recognised, however, that there is an urgent need to investigate the composition and dynamic behaviour of the Earth's atmosphere. The ERS-2 Programme approval therefore included an experimental sensor for atmospheric research, the 'Global Ozone Monitoring Experiment' (GOME), which is essentially a scaled-down version of the SCIAMACHY instrument proposed for the European Polar Platform to be launched at the end of the century.

The inclusion of the GOME sensor in ERS-2 Programme was endorsed on the explicit understanding that:
- the sensor would be developed, tested, calibrated and integrated in the same time frame as the satellite and the other instruments would be rebuilt
- the resource demands of the sensor would have to be satisfied from the existing system margins, imposing stringent limitations on mass, power and data rate
- no major upgrades in the ERS Ground Segment would be needed, and the financial burden for the data-processing algorithms and software would be borne by scientific institutions and/or national agencies.

The limitations on resources have already led to drastic changes in the instrument concept, because at the Baseline Design Review held in February 1991 it became obvious that the power/energy demand exceeded the available margin. Instead of GOME having its own interface to the On-Board Computer (OBC) and to the Instrument Data Handling and Transmission (IDHT) system, it was decided to provide these functions via the existing interfaces of the Along-Track Scanning Radiometer (ATSR) instrument.

Scientific objectives

Ozone (O_3) is a tri-atomic form of oxygen, formed by hard ultraviolet radiation in the atmospheric layer between about 15 and 45 km altitude, the so-called 'stratosphere'. It absorbs radiation in the spectral region between 240 and 310 nm, preventing these harmful rays from reaching the ground in large quantities. This naturally protective atmospheric layer is now being threatened by human activities, in particular by the steady release of chlorfluorocarbons (CFCs) into the atmosphere. The accumulated anthropogenic effects on stratospheric ozone are believed to be causing a steady depletion of the ozone layer by approximately 0.3 % per year.

The chemistry of the stratosphere is very complex. The hard ultraviolet radiation causes the breakup of many of the available species into reactive fragments, which lead to a multitude of possible reactions. Normally, the rates of these reactions depend not only on the nature of the species, but also on local pressure, temperature, radiative fluxes in the different wavelength regions, vertical and horizontal transport processes, etc. Thus, in order to understand the ozone chemistry fully, it is not sufficient just to measure the ozone; one must also monitor the abundances of many other species, including very

reactive intermediate species occurring in only very low concentrations.

Reflecting this need, GOME is intended to measure other species as well as to observe aerosols and polar stratospheric clouds which play significant roles in the heterogeneous processes associated with ozone chemistry. It is hoped that some of these species may be observed in the troposphere, another part of the atmosphere believed to be affected by man's activities. However, the presence of clouds may make this difficult.

For this GOME will exploit spectroscopy, which is a viable technique for observing trace species in the atmosphere. Sunlight, reflected by the ground surface and scattered within the different atmospheric layers, carries the absorption signatures of the absorbing species (Figs. 1 & 2). The GOME instrument is designed to collect this light over the entire wavelength region from 240 to 790 nm, in which not only ozone, but also a number of other atmospheric species absorb. In addition to the classical backscatter technique, the GOME instrument exploits the novel technique of 'Differential Absorption Spectroscopy' (DOAS)*.

Satellite mission and instrument accommodation

Like its predecessor ERS-1, ERS-2 will fly in a Sun-synchronous polar orbit with an inclination of 98°, with a mean altitude of 780 km and a local time of 10.30 h for the equator crossing on the descending node. This results in an orbital period of approximately 100 min and a ground speed for the subsatellite point of 7 km/s.

The GOME instrument's instantaneous field of view has been chosen to be 40 km x 2 km, or 2.8° x 0.14°. Via the

* Developed by U. Platt (Heidelberg, FRG)

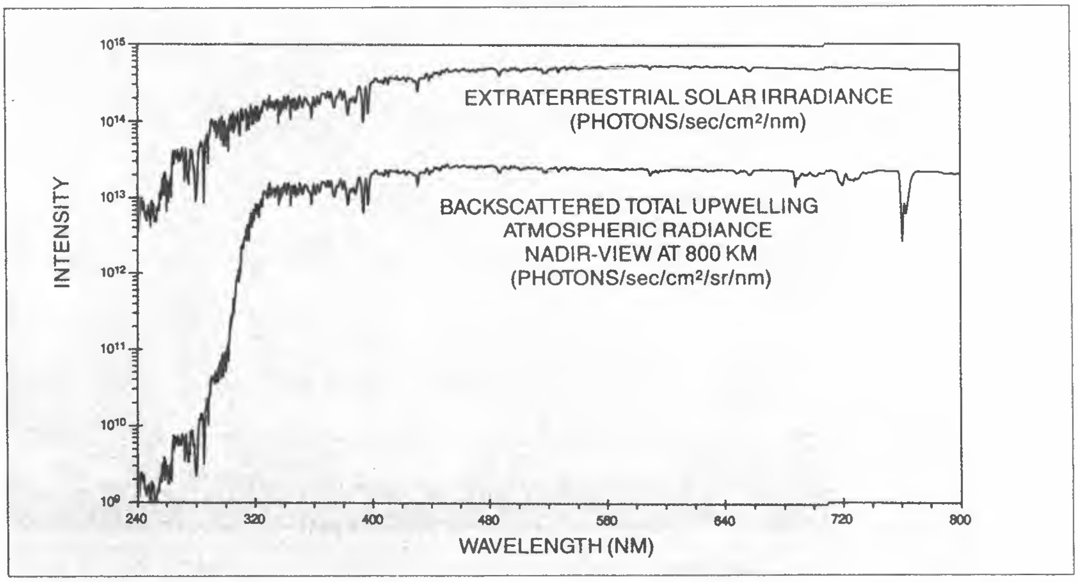


Figure 1. LOWTRAN simulation of spectral radiances at the top of the atmosphere in the wavelength range of the GOME instrument, i.e. 240–790 nm

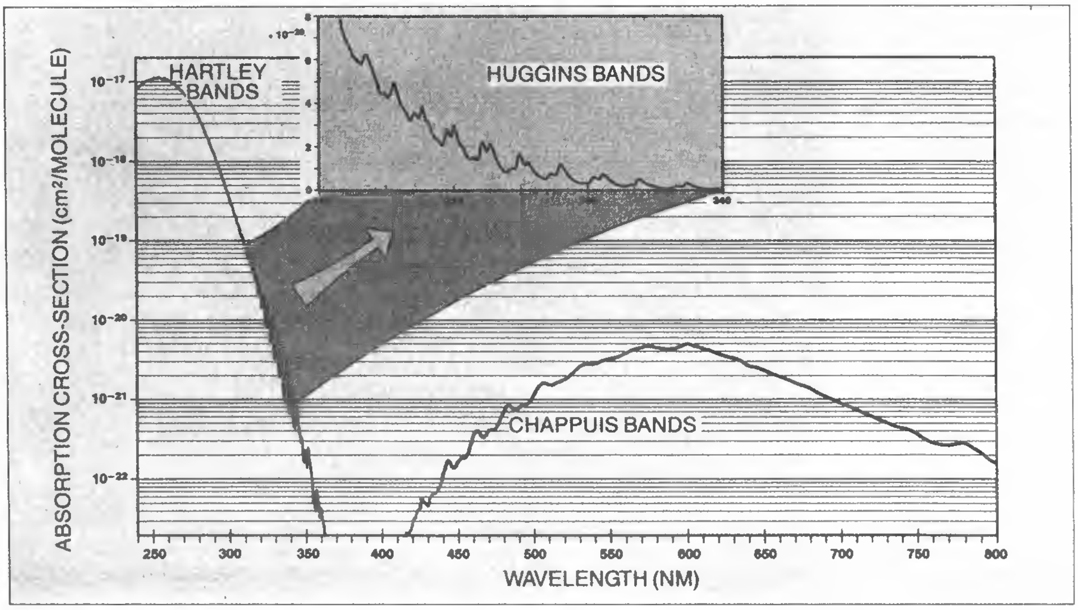


Figure 2. Ozone absorption cross-sections in the wavelength range of the GOME instrument

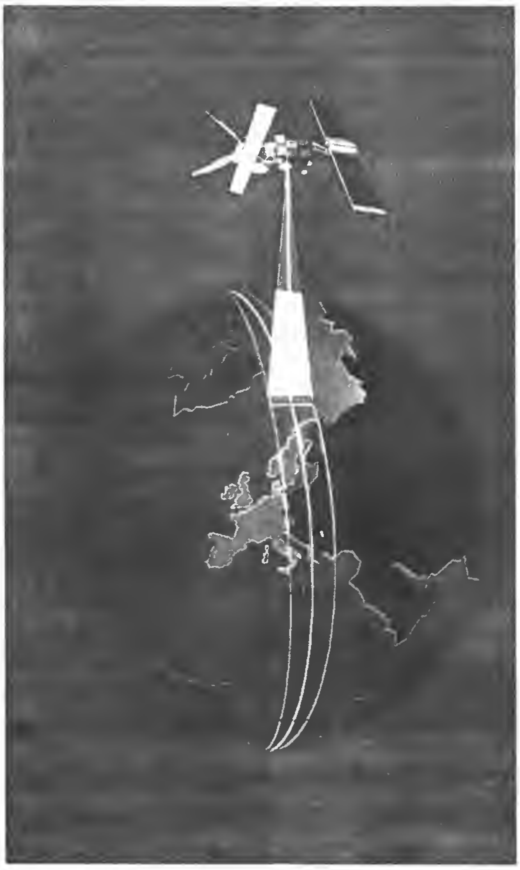
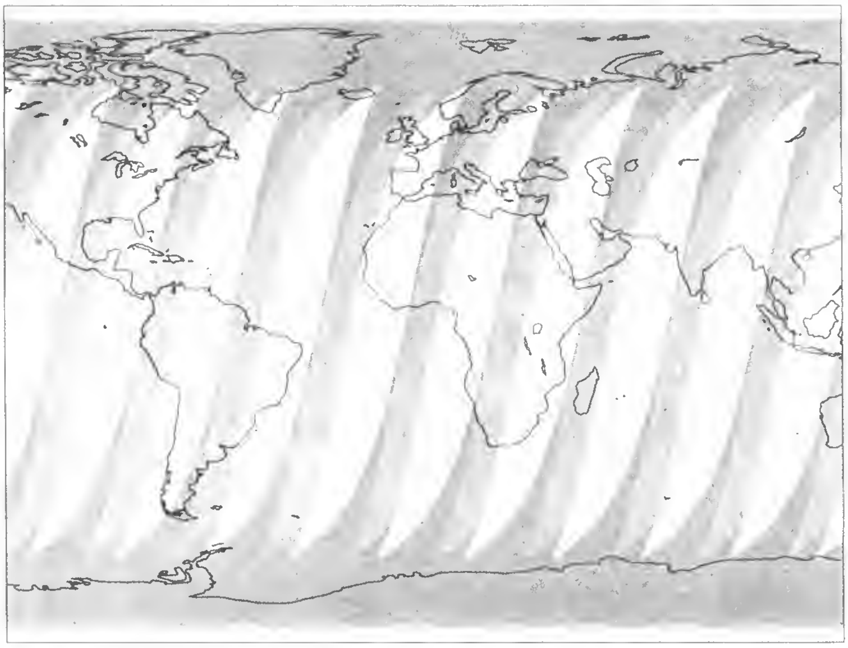
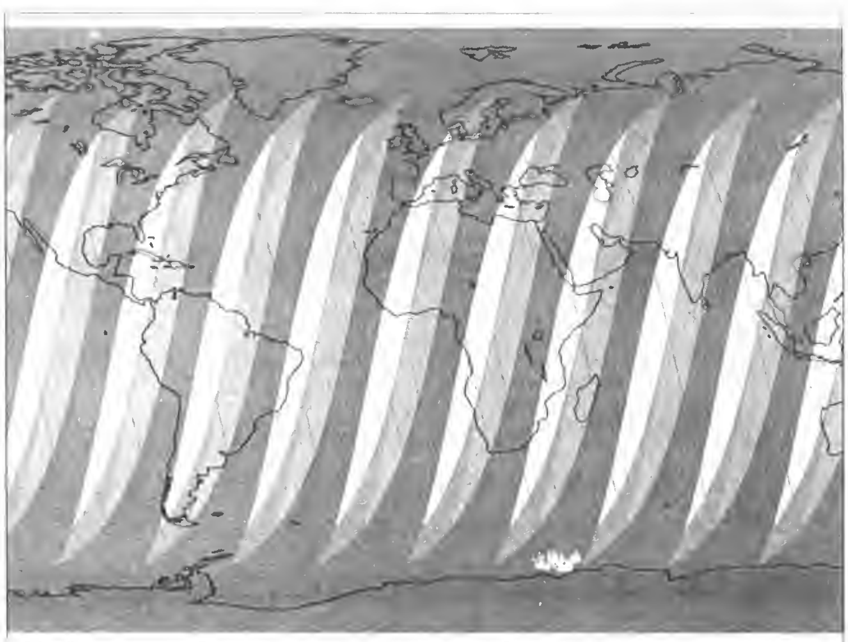


Figure 3. Artist's impression of the GOME instrument's scanning geometry



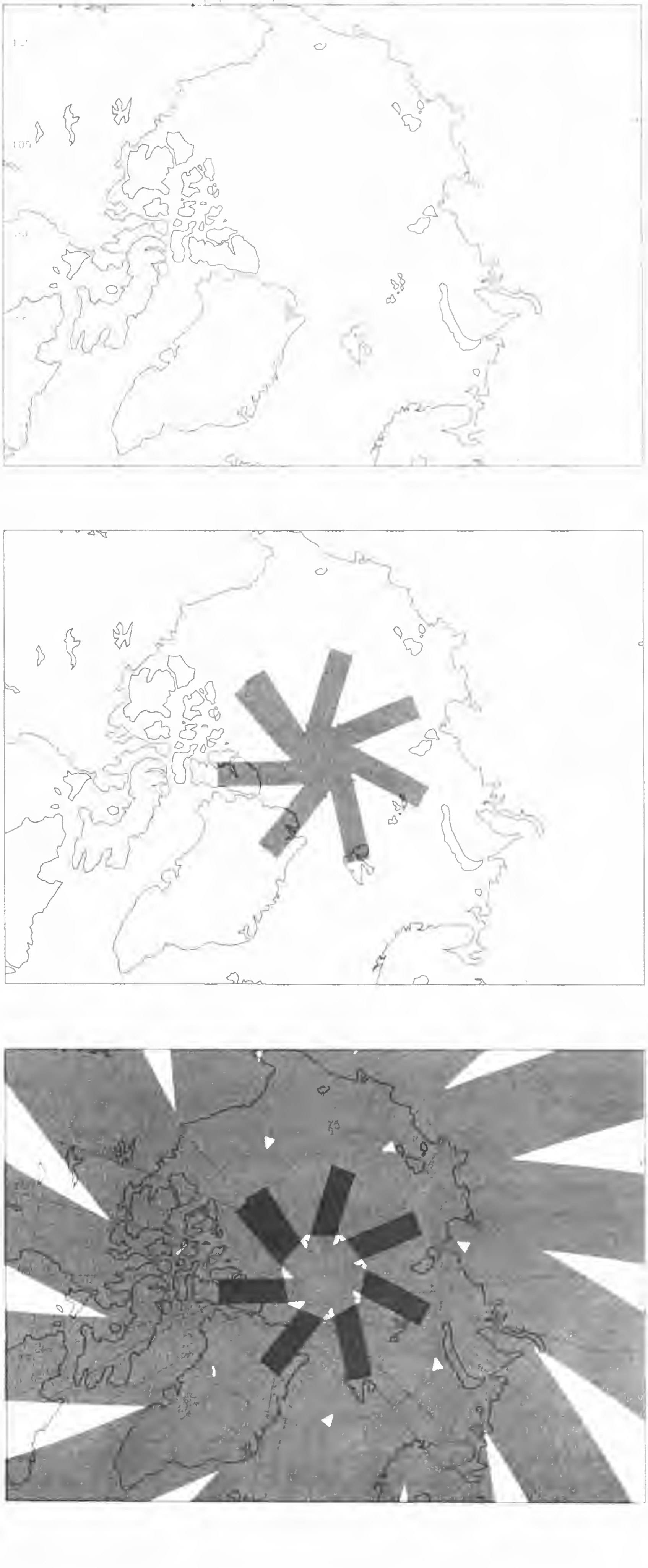


movement of the instrument's scanning mirror, this instantaneous field of view can be scanned across the satellite's track. With a ±31° scan, global coverage can be achieved within 3 days, except for a gap of approximately 4° around both poles. To overcome this limitation, a special pole-viewing mode has been included (Figs. 3 & 4a,b).

The GOME instrument is mounted externally, on the surface of the payload module facing in the flight direction (i.e. the −Y face), with a clear field of view in the nadir direction (Fig. 5). It is thermally decoupled from the spacecraft structure as far as possible.

Photon flux computations show that for the visible/near-infrared channels, a good signal-to-noise ratio can be achieved with a 1.5 s integration time on the detector. The time for one forward scan has therefore been set to 4.5 s. For the flyback of the scanning mirror, another 1.5 s have been allowed, resulting in the scan pattern shown in Figure 6, with a ground pixel size of 320 km x 40 km.

Figure 4a. Three-day coverage map for GOME



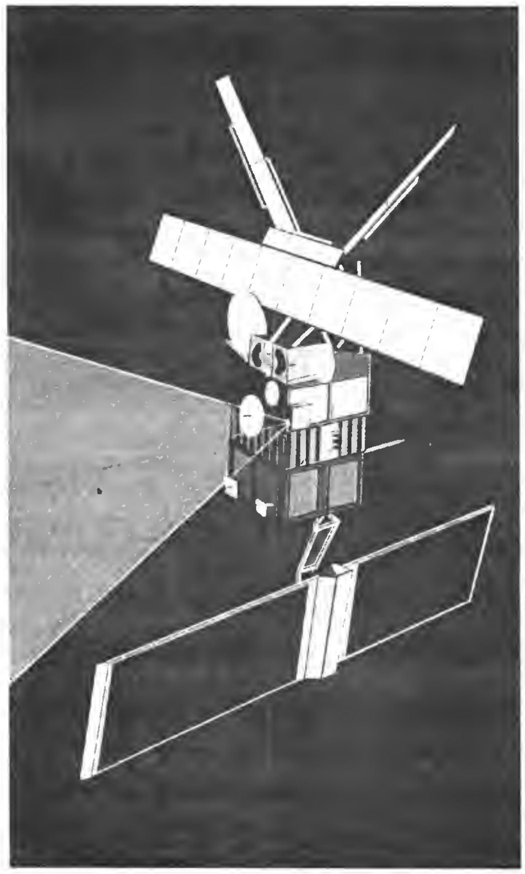


Figure 5. Artist's impression of the GOME instrument aboard ERS-2

The instrument's design

As a general principle, the GOME instrument collects light arriving from the Sun-illuminated Earth's atmosphere and decomposes it into its spectral components. In order to provide both the required spectral coverage from 240 to 790 nm and a good spectral resolution of 0.2–0.4 nm, this decomposition is done in two steps: first by a quartz pre-disperser prism, in which the light is split into four different channels. Each of these channels contains a grating as second dispersing element, and a 1024-pixel silicon array detector (the integration times on the chip can be multiples of 93.75 ms, with 1.5 s for the visible and 30 s for the ultraviolet being the default values).

The entire GOME instrument can be broken down into the following functional blocks:

- the spectrometer
- the four Focal-Plane Assemblies (FPAs)
- the Calibration Unit
- the scan unit with the scanning mechanism and the scan unit electronics (SEU) assembly

Figure 4b. Three-day coverage map for GOME

- the Polarisation Measurement Device (PMD)
- the Digital Data Handling Unit (DDHU)
- the optical bench structure
- the thermal control hardware.

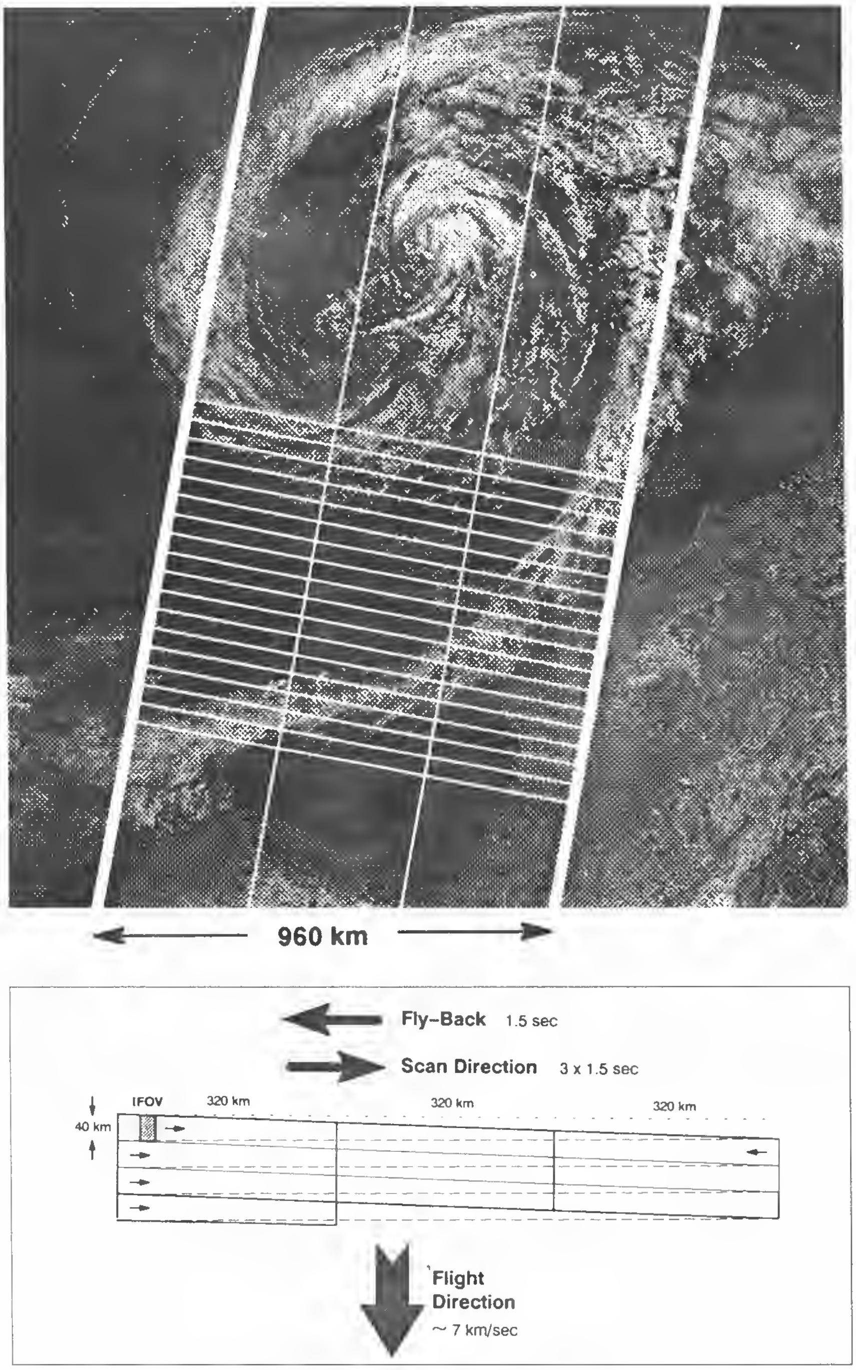


Figure 6. GOME scan pattern (graphic courtesy of DLR, Oberpfaffenhofen)

Table 1. Key optics performance parameters

Band	Wavelength range (nm)	Grating (l/mm)	Pixel resolution (nm)	Spectral resolution (nm)
1A	240—268	3600	0.11	0 22
1B	268—295			
2A	290—312	2400	0 12	0 24
2B	312—405			
3	400—605	1200	0.2	0.4
4	590—790	1200	0 2	0 4

Spectrometer optics

In the spectrometer optics, shown schematically in Figure 7, the light reflected off the scanning mirror is focussed by an anamorphic telescope such that the shape of the focus matches the entrance slit of the spectrometer (dimensions 10 mm x 100 µm. After the slit, the light is collimated by an off-axis parabolic mirror. It then strikes the quartz pre-disperser prism, causing a moderately wavelength dispersed beam. Another prism acts as channel separator: the upper edge of this prism reaches into the wavelength-dispersed beam, letting the longer wavelengths pass, reflecting the wavelength range 290–405 nm into Channel 2 by means of a dielectric reflecting coating, and guiding the wavelength range 240–295 nm internal to the prism into Channel 1. The unaffected wavelength range of 405–790 nm is then split up by a dichroic beam splitter into Channels 3 (400–605 nm) and 4 (590–790 nm).

Each individual channel consists of an off-axis parabola, a grating, and an objective with f-numbers of 2 (Channels 1 and 2) and 3 (Channels 3 and 4), finally focussing the light onto the detectors contained in their respective Focal-Plane Assemblies.

The most critical optical elements in the optical chain are the diffraction gratings, which have to provide both a high efficiency in the first diffraction order and a very low level of stray light and ghosting. Because of the criticality of the gratings for the final performance of the instrument, two parallel development programmes are under way, at the firms of Jobin-Yvon in France and Carl Zeiss in Germany. Some of the key performance requirements for the optics are summarised in Table 1.

Focal-Plane Assemblies

The FPAs are made from titanium and have a sealed quartz window at the side where they are flanged to the respective objective tubes. The rear side of the FPA, the so-called 'pin-plate', is a titanium plate provided with electrically isolated, vacuum-tight feed-throughs for the electrical connections to the detector. This is a Reticon RL 1024 SR random-access diode array detector with 1024 pixels, each pixel measuring 25 µm in the dispersion direction and 2.5 mm in the along-slit direction. Each diode is randomly accessible by an address bus and can be read out individually.

In the GOME instrument, the detectors of Channels 1 and 2 are split into several

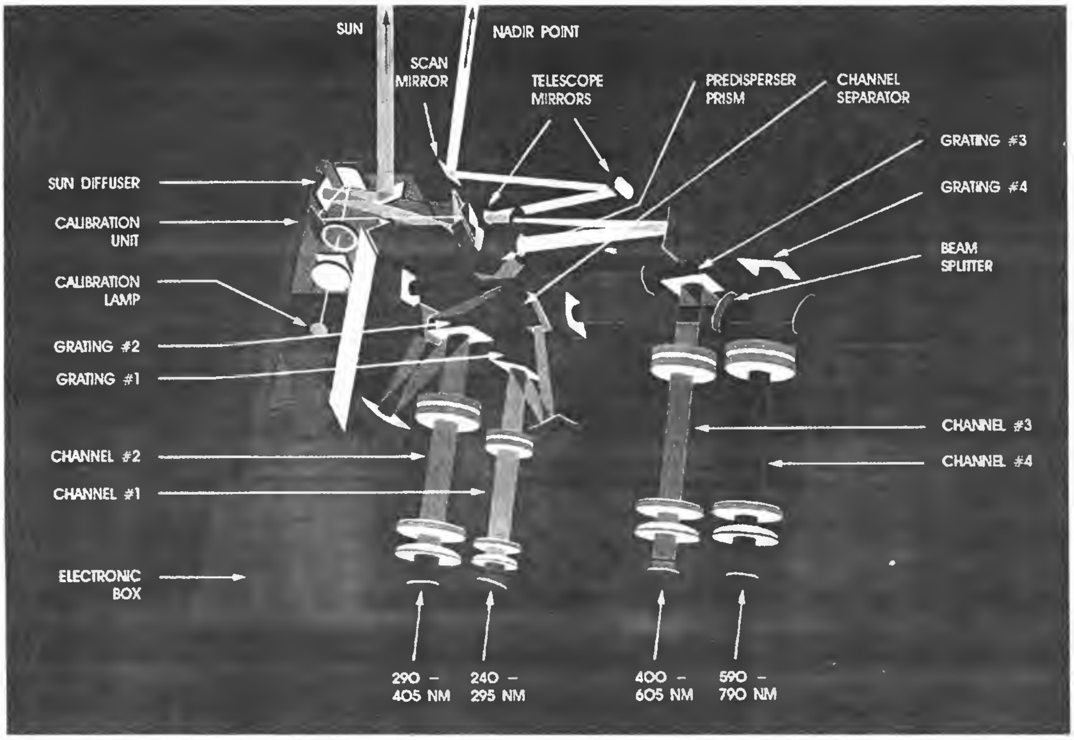


Figure 7. Spectrometer optics

bands, the integration times of which may be varied individually. The Reticon detector chip is shown in Figure 8. The detectors are glued onto two-stage Peltier coolers, which reduce their temperature to −40°C to keep the dark current of the photodiodes sufficiently low. The hot side of the Peltier coolers is glued (in the engineering model), respectively brazed (in the flight model), to a copper bar, extending through the pin-plate. Outside the FPA, this copper bar is connected via flexible connections and heat pipes to the main radiator. The tips carrying the Peltier coolers and detectors are tilted between 1.6° and 9.5°, to compensate for chromatic aberration.

At the back side of the FPA, the Front-End Electronics (FEE) are mounted on a printed-circuit board. They are based on a charge amplifier implemented with a low-noise amplifier and a dual-FET input stage. The output of the FEE is fed to the Digital Data Handling Unit (DDHU), where it is further processed and digitised.

During ground operations, the FPAs can be either evacuated, or filled with dry nitrogen to avoid moisture freezing out on the cooled detectors. In addition, the polarity of the Peltier elements can be inverted to heat the detectors to +80° to drive off possible contaminants and to anneal radiation effects. Once in orbit, the FPAs are exposed to the vacuum of space by a burst membrane, which is designed to open during the launch phase.

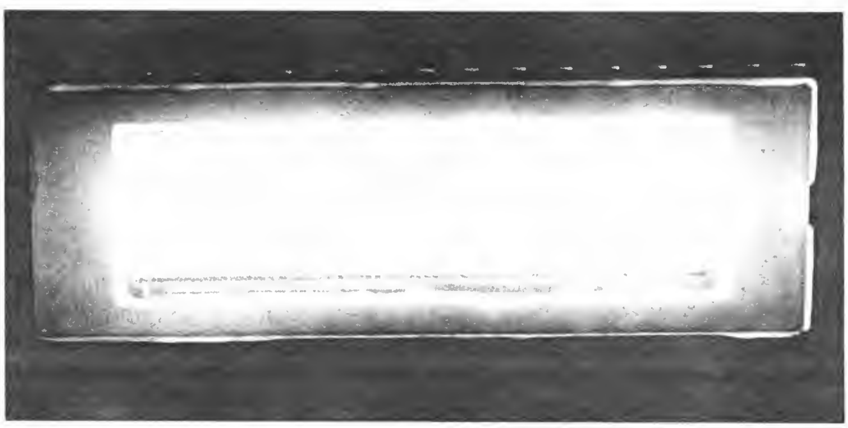
Calibration unit

In order to support the DOAS technique, one would like to have a wavelength stability of 1/100 th of a pixel. This is not achievable with a passive thermal design in such a power-limited situation. Instead, wavelength position on the detector pixels versus orbital temperature will be mapped by means of a hollow-cathode lamp (Pt-Cr-Ne) which provides a sufficient number of sharp lines in all wavelength regions.

For the radiometric calibration, the Sun will be used as the source. Because of the orbital and scanner geometry, which prevents direct viewing of the Sun via the scanning mirror, and because its high intensity would lead (even with the shortest possible integration time) to detector saturation, the Sun is viewed via a diffuser plate accommodated in the calibration unit (Fig. 9).

Previous NASA experience has shown that the diffuser is subject to degradation during its periods of exposure. Precautions are therefore taken by having:

Figure 8. Reticon RL1024SR detector chip



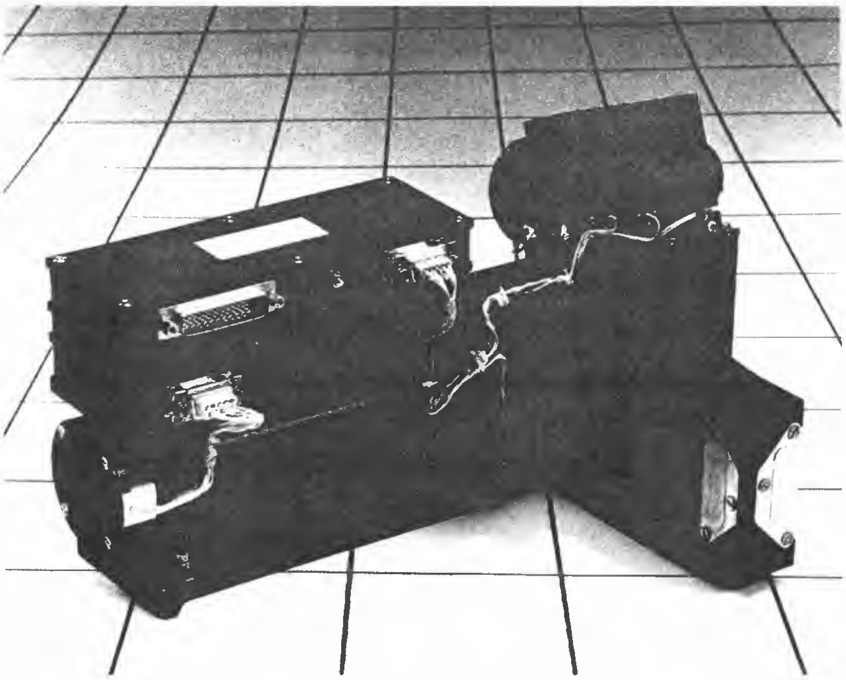


Figure 9. Calibration unit

- a mesh in front of the diffuser, attenuating the incoming light level and largely protecting the diffuser
- a shutter mechanism that opens only during Sun calibration and protects the diffuser during the remaining mission phases
- the possibility to view the calibration lamp via the diffuser, thereby having a means to monitor possible degradation, at least at those wavelengths provided by the lamp.

Scanning unit
The scanning unit consists of two separate assemblies, the Scan Mechanism (SM) and the Scan Unit Electronics Assembly (SUEA). The scan mechanism is located on the optical bench, with its rotation axis aligned with the satellite's flight direction. The axis carries a glued-on aluminium-coated mirror, which can be heated from the rear to drive off possible contaminants, if necessary.

A brushless DC motor actuates the scanner, the position of which is sensed by a resolver. The rotating part of the resolver, the mirror heater and the temperature sensor are connected to the static part via a flexible printed-circuit connection. The angular range of the scanner is limited to −63.8 to +192.2° with respect to nadir (0°) by software and end stops.

The rotation axis is supported by two spring-preloaded angular contact bearings, the balls of which are ion-plated with lead and the races are made of lead bronze. All structural parts (housing, pivot, etc.) are made from titanium.

Polarisation measurement device
The incoming light from the Earth's atmosphere can be partially polarised. Because the instrument's responses to the two orthogonal linear polarisation directions are not equal, there is a need to monitor the polarisation of the incoming light.

In the pre-disperser prism, light is internally reflected at the Brewster angle. About 5 % of this light, polarised normal to the plane of incidence, leaks away at this surface. This light is collected by an off-axis parabola, reflected by a mirror out of the plane of the optical bench, and then sensed by a custom-made photodiode array.

Because the device is not temperature-controlled, it is subject to drifts. To keep the impact of changing temperatures to a minimum, a second array of photodiodes with the same geometry, but not exposed to light, will be used to compensate for the dark current and its variability with temperature

The measured signals are acquired by the DDHU, converted to digital signals, and included into the telemetry data (3 x 16 bit, 10.67 Hz).

Digital Data-Handling Electronics (DDHU)
The prime interface to the satellite's electrical subsystems is via the Digital Electronics Unit (DEU) of the Along-Track Scanning Radiometer (ATSR). Because the DEU now not only controls the ATSR's Infrared Radiometer (IRR) and Microwave Radiometer (MWR), but also GOME, a redundant DEU has been added, together with a DEU Switching Unit (DSU).

The DEU assumes all the normal functions of an Instrument Control Unit (ICU). Commands dedicated to GOME are expanded into a serial digital bit stream, initiating the appropriate actions within the DDHU. In the opposite direction, both housekeeping and scientific data are written by the DDHU into data buffers, from which they are requested by the DEU to be put into predefined fields of the ATSR S-band and X-band data streams.

Thermal-control hardware
The most critical aspect of the thermal control is the detector temperature, which is provided by the Peltier elements in each of the Focal-Plane Assemblies. The hot sides of the Peltiers are all connected, via copper bars and flexible connections, to a parallel pair of bent heat pipes, which end in the primary radiator exposed to deep space.

The DDHU and the scanning mirror electronics assembly have their own radiative surfaces for thermal control. The remainder of the instrument is wrapped in multi-layer insulation blankets. For cold non-operational phases, thermostat-controlled heater mats and resistors are directly powered from the payload's Power Distribution Unit.

Structure

All elements of the optics, mechanisms, electronics and thermal hardware are mounted on the optical bench, which is a nearly rectangular aluminium plate with stiffening ribs beneath. This optical bench is carried on four feet, one of which is round in cross-section and rather stiff. The other three are blade-shaped feet, with their flexing direction lying in the direction of the fixed foot. This prevents mechanical distortion of the optical alignment due to thermal expansion of the bench.

Beneath the optical bench, in the space between the ribs, the harness and the pipework for FPA evacuation are routed. An EMC shield protects the instrument from electromagnetic interference from the satellite's radars and communications system.

Operations

The GOME instrument has numerous measurement, calibration, and support modes. In particular, due to the varying light levels that will be experienced during each orbit, integration time settings will have to be adjusted frequently. In addition, once per day a Sun calibration has to be performed.

In order to limit the command traffic on the uplink, the DEU stores three different timelines, each of which can be activated automatically up to 16 times in sequence. One of these timelines is for normal operations, one for an orbit in which a Sun calibration is being performed, and one with a sidewards swath to cover the polar area (with the normal nadir-centred swath there would be a gap in coverage of about 4° around both poles).

About once per month, a wavelength mapping as function of the thermal variations will be performed with the wavelength calibration lamp. On these occasions a diffuser characterisation can also be carried out.

Lunar observations, which are restricted by the Sun–Moon–satellite scanner field-of-view geometry, will be performed whenever possible.

Data processing

GOME data will arrive together with the other 'low-bit-rate' data at the various ground stations to which the ERS tape recorders are downlinked. Extracted GOME data, together with orbit and attitude information, will then be shipped on Exabyte cassettes to the German Processing and Archiving Facility (D-PAF) in Oberpfaffenhofen. In a first processing step, the raw data will be corrected for instrument-induced errors and drifts, and provided with information on geo-location, Sun aspect angle, etc.

From these radiometrically and wavelength corrected geo-located spectra, the ozone total column amount, ozone vertical concentration profile, and data on aerosol loading and cloud cover can be retrieved. This will be done at distributed centres, according to the particular scientific expertise available. Time and budgets permitting, other atmospheric-constituent retrieval can be added to the range of data products generated. Finally, time and spatial averaging for long-term global-trend analyses is likely to be conducted (not yet specifically defined).

In addition to this off-line processing chain, some limited processing capabilities will also be installed at ESTEC, in order to evaluate the instrument performance after launch, optimise parameter settings and operating schemes, and to support possible scientific campaigns.

GOME should produce unique data as there will be no other instrument available on its time scale which duplicates its capabilities. The instrument fills a critical slot as far as future observing strategies are concerned, and GOME could well become the prototype for subsequent ozone-monitoring instruments. Its medium spectral resolution combined with a wide spectral range and absolute calibration is particularly important as it means that, in addition to applying the traditional backscatter approach, one can also use differential optical absorption spectroscopy to retrieve data with GOME.

Acknowledgements

We gratefully acknowledge the unfailing support of the GOME Science Team, headed by Prof. Dr. J. Burrows from the University of Bremen (D). Much of the work reported here has been done by the GOME Industrial Team, comprised of Officine Galileo (I), Laben (I), TPD/TNO (NL), Dornier (D) and the Rutherford Appleton Laboratory (UK), and BAe (UK) for the DEU modifications.

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Scientific objectives

Ozone (O_3) is a tri-atomic form of oxygen, formed by hard ultraviolet radiation in the atmospheric layer between about 15 and 45 km altitude, the so-called 'stratosphere'. It absorbs radiation in the spectral region between 240 and 310 nm, preventing these harmful rays from reaching the ground in large quantities. This naturally protective atmospheric layer is now being threatened by human activities, in particular by the steady release of chlorfluorocarbons (CFCs) into the atmosphere. The accumulated anthropogenic effects on stratospheric ozone are believed to be causing a steady depletion of the ozone layer by approximately 0.3 % per year.

The chemistry of the stratosphere is very complex. The hard ultraviolet radiation causes the breakup of many of the available species into reactive fragments, which lead to a multitude of possible reactions. Normally, the rates of these reactions depend not only on the nature of the species, but also on local pressure, temperature, radiative fluxes in the different wavelength regions, vertical and horizontal transport processes, etc. Thus, in order to understand the ozone chemistry fully, it is not sufficient just to measure the ozone; one must also monitor the abundances of many other species, including very

reactive intermediate species occurring in only very low concentrations.

Reflecting this need, GOME is intended to measure other species as well as to observe aerosols and polar stratospheric clouds which play significant roles in the heterogeneous processes associated with ozone chemistry. It is hoped that some of these species may be observed in the troposphere, another part of the atmosphere believed to be affected by man's activities. However, the presence of clouds may make this difficult.

For this GOME will exploit spectroscopy, which is a viable technique for observing trace species in the atmosphere. Sunlight, reflected by the ground surface and scattered within the different atmospheric layers, carries the absorption signatures of the absorbing species (Figs. 1 & 2). The GOME instrument is designed to collect this light over the entire wavelength region from 240 to 790 nm, in which not only ozone, but also a number of other atmospheric species absorb. In addition to the classical backscatter technique, the GOME instrument exploits the novel technique of 'Differential Absorption Spectroscopy' (DOAS)*.

Satellite mission and instrument accommodation

Like its predecessor ERS-1, ERS-2 will fly in a Sun-synchronous polar orbit with an inclination of 98°, with a mean altitude of 780 km and a local time of 10.30 h for the equator crossing on the descending node. This results in an orbital period of approximately 100 min and a ground speed for the subsatellite point of 7 km/s.

The GOME instrument's instantaneous field of view has been chosen to be 40 km x 2 km, or 2.8° x 0.14°. Via the

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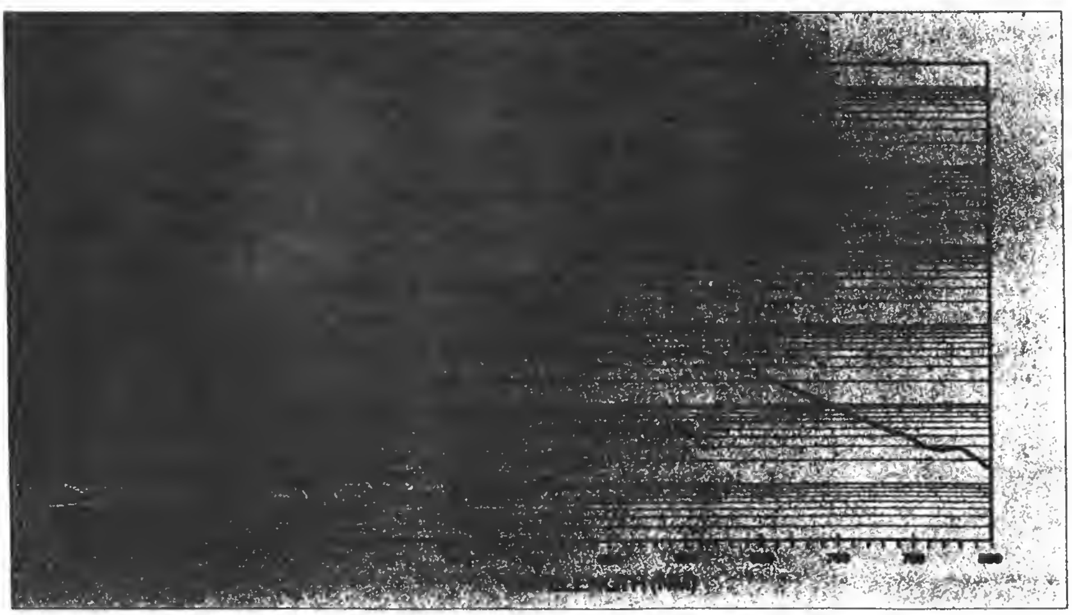
Figure 1. LOWTRAN simulation of spectral radiances at the top of the atmosphere in the wavelength range of the GOME instrument, i.e. 240–790 nm



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movement of the instrument's scanning mirror, this instantaneous field of view can be scanned across the satellite's track. With a ±31° scan, global coverage can be achieved within 3 days, except for a gap of approximately 4° around both poles. To overcome this limitation, a special pole-viewing mode has been included (Figs. 3 & 4a,b).

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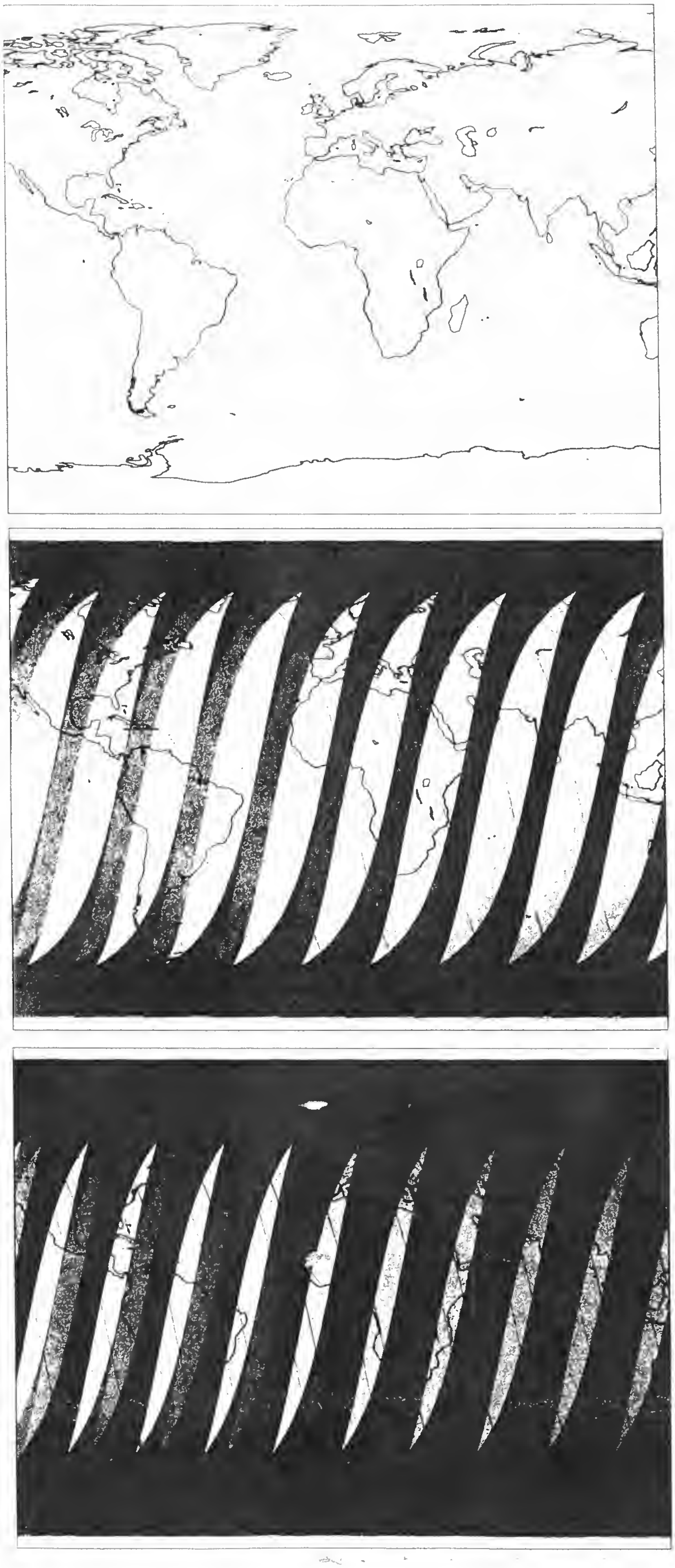
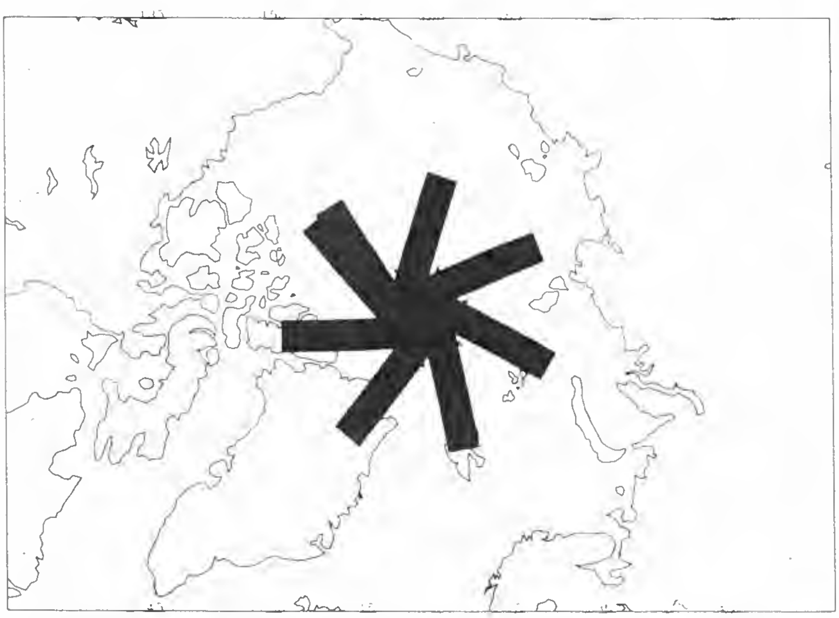
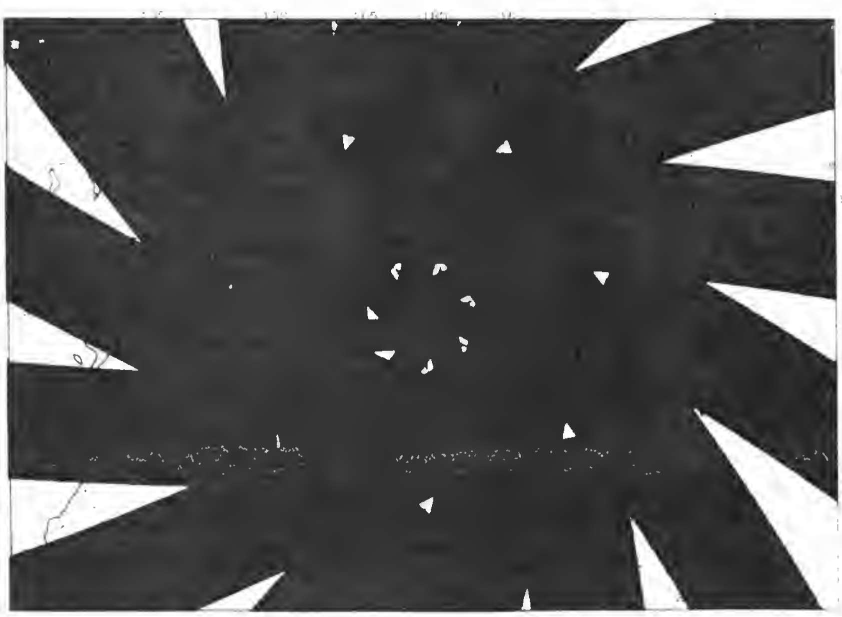


Figure 4a. Three-day coverage map for GOME





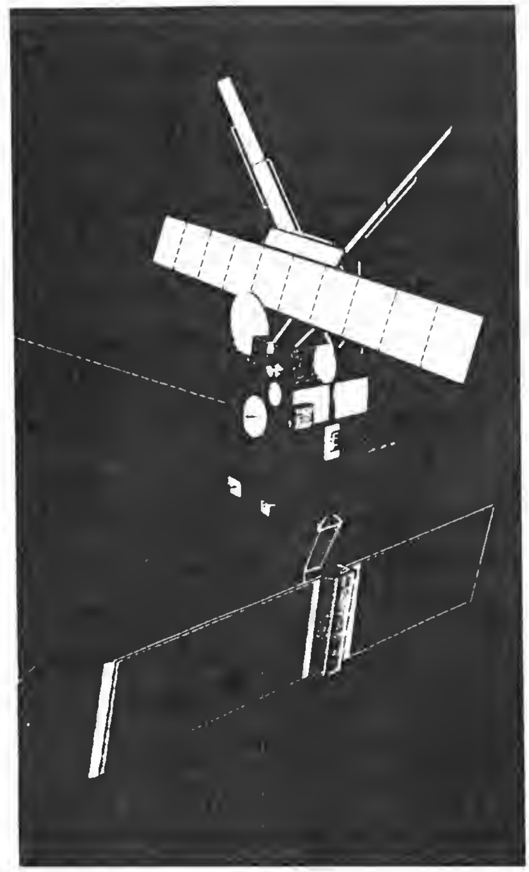


Figure 5. Artist's impression of the GOME instrument aboard ERS-2

The instrument's design

As a general principle, the GOME instrument collects light arriving from the Sun-illuminated Earth's atmosphere and decomposes it into its spectral components. In order to provide both the required spectral coverage from 240 to 790 nm and a good spectral resolution of 0.2–0.4 nm, this decomposition is done in two steps: first by a quartz pre-disperser prism, in which the light is split into four different channels. Each of these channels contains a grating as second dispersing element, and a 1024-pixel silicon array detector (the integration times on the chip can be multiples of 93.75 ms, with 1.5 s for the visible and 30 s for the ultraviolet being the default values).

The entire GOME instrument can be broken down into the following functional blocks:
- the spectrometer
- the four Focal-Plane Assemblies (FPAs)
- the Calibration Unit
- the scan unit with the scanning mechanism and the scan unit electronics (SEU) assembly

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– the Digital Data Handling Unit (DDHU)
– the optical bench structure
– the thermal control hardware.

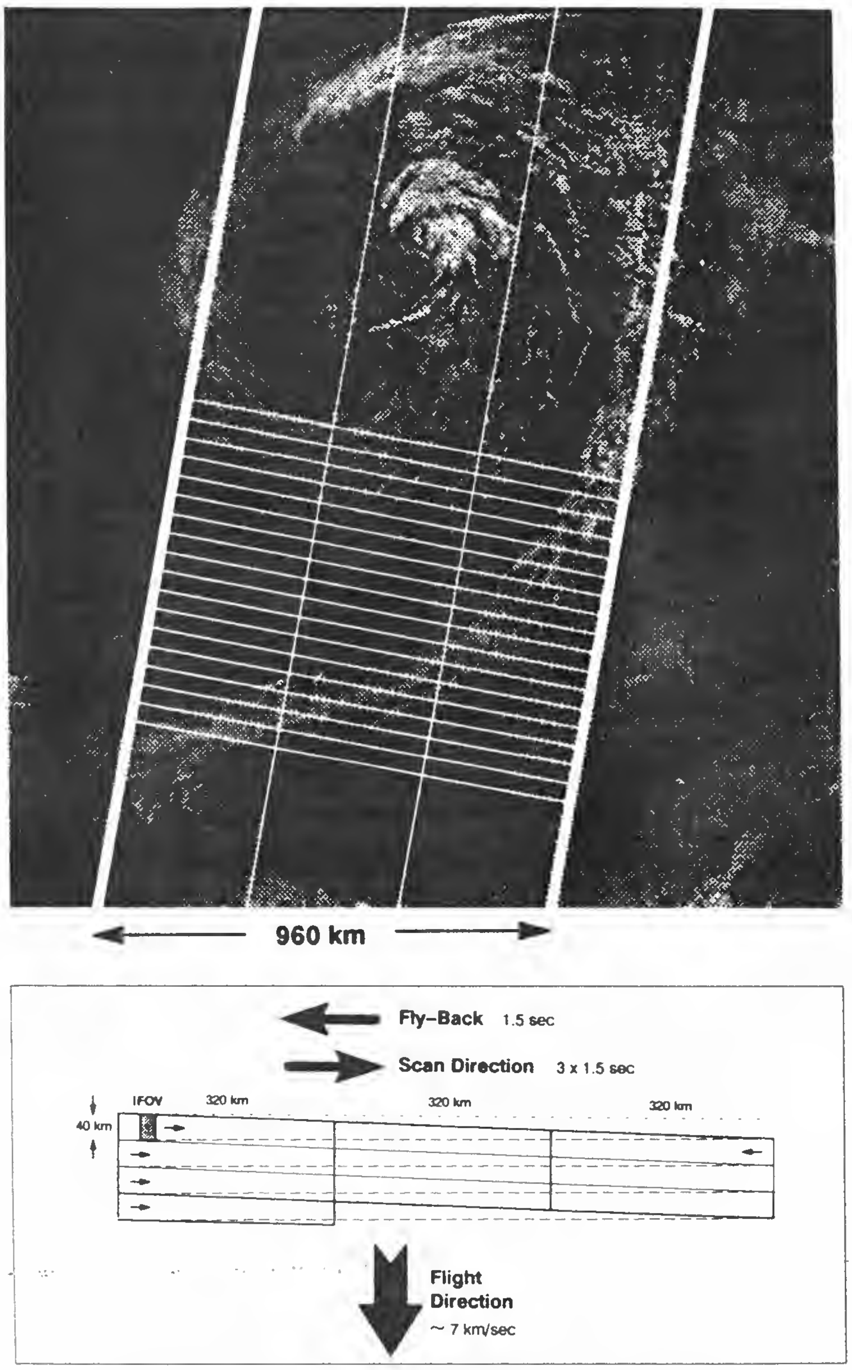


Figure 6. GOME scan pattern (graphic courtesy of DLR, Oberpfaffenhofen)

Table 1. Key optics performance parameters

Band	Wavelength range (nm)	Grating (l/mm)	Pixel resolution (nm)	Spectral resolution (nm)
1A	240–268	3600	0.11	0.22
1B	268–295			
2A	290–312	2400	0.12	0.24
2B	312–405			
3	400–605	1200	0.2	0.4
4	590–790	1200	0.2	0.4

Spectrometer optics

In the spectrometer optics, shown schematically in Figure 7, the light reflected off the scanning mirror is focussed by an anamorphic telescope such that the shape of the focus matches the entrance slit of the spectrometer (dimensions 10 mm x 100 μm. After the slit, the light is collimated by an off-axis parabolic mirror. It then strikes the quartz pre-disperser prism, causing a moderately wavelength dispersed beam. Another prism acts as channel separator: the upper edge of this prism reaches into the wavelength-dispersed beam, letting the longer wavelengths pass, reflecting the wavelength range 290–405 nm into Channel 2 by means of a dielectric reflecting coating, and guiding the wavelength range 240–295 nm internal to the prism into Channel 1. The unaffected wavelength range of 405–790 nm is then split up by a dichroic beam splitter into Channels 3 (400–605 nm) and 4 (590–790 nm).

Each individual channel consists of an off-axis parabola, a grating, and an objective with f-numbers of 2 (Channels 1 and 2) and 3 (Channels 3 and 4), finally focussing the light onto the detectors contained in their respective Focal-Plane Assemblies.

The most critical optical elements in the optical chain are the diffraction gratings, which have to provide both a high efficiency in the first diffraction order and a very low level of stray light and ghosting. Because of the criticality of the gratings for the final performance of the instrument, two parallel development programmes are under way, at the firms of Jobin-Yvon in France and Carl Zeiss in Germany. Some of the key performance requirements for the optics are summarised in Table 1.

Focal-Plane Assemblies

The FPAs are made from titanium and have a sealed quartz window at the side where they are flanged to the respective objective tubes. The rear side of the FPA, the so-called 'pin-plate', is a titanium plate provided with electrically isolated, vacuum-tight feed-throughs for the electrical connections to the detector. This is a Reticon RL 1024 SR random-access diode array detector with 1024 pixels, each pixel measuring 25 μm in the dispersion direction and 2.5 mm in the along-slit direction. Each diode is randomly accessible by an address bus and can be read out individually.

In the GOME instrument, the detectors of Channels 1 and 2 are split into several

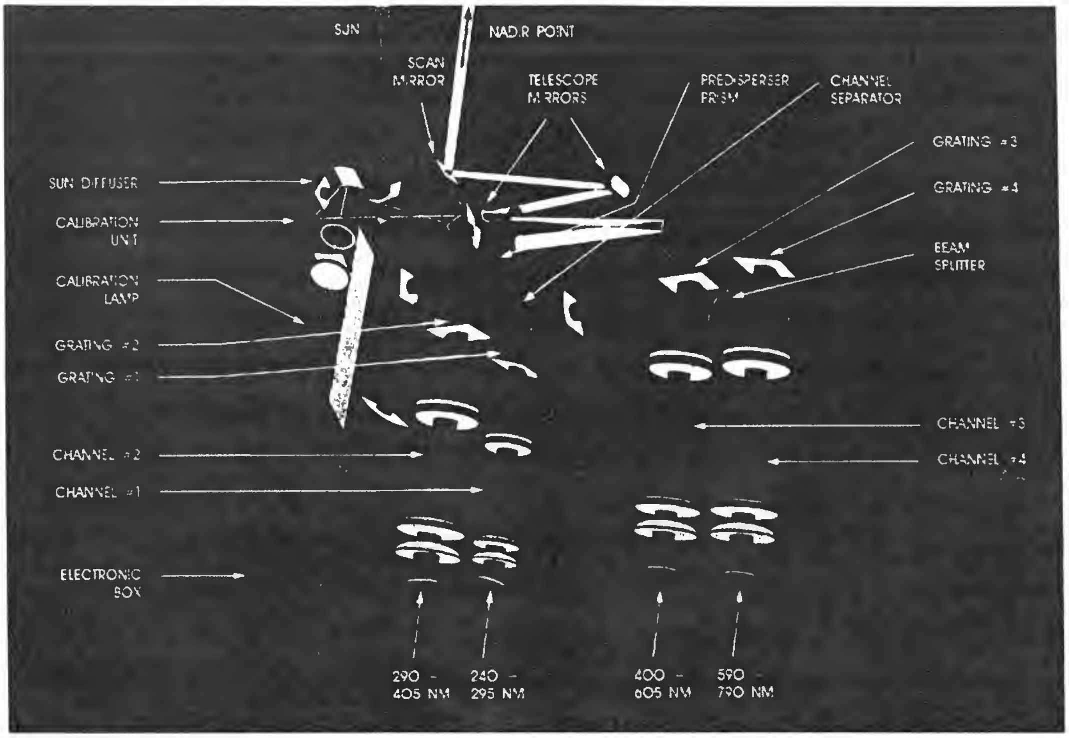


Figure 7. Spectrometer optics

bands, the integration times of which may be varied individually. The Reticon detector chip is shown in Figure 8. The detectors are glued onto two-stage Peltier coolers, which reduce their temperature to −40°C to keep the dark current of the photodiodes sufficiently low. The hot side of the Peltier coolers is glued (in the engineering model), respectively brazed (in the flight model), to a copper bar, extending through the pin-plate. Outside the FPA, this copper bar is connected via flexible connections and heat pipes to the main radiator. The tips carrying the Peltier coolers and detectors are tilted between 1.6° and 9.5°, to compensate for chromatic aberration.

At the back side of the FPA, the Front-End Electronics (FEE) are mounted on a printed-circuit board. They are based on a charge amplifier implemented with a low-noise amplifier and a dual-FET input stage. The output of the FEE is fed to the Digital Data Handling Unit (DDHU), where it is further processed and digitised.

During ground operations, the FPAs can be either evacuated, or filled with dry nitrogen to avoid moisture freezing out on the cooled detectors. In addition, the polarity of the Peltier elements can be inverted to heat the detectors to +80° to drive off possible contaminants and to anneal radiation effects. Once in orbit, the FPAs are exposed to the vacuum of space by a burst membrane, which is designed to open during the launch phase.

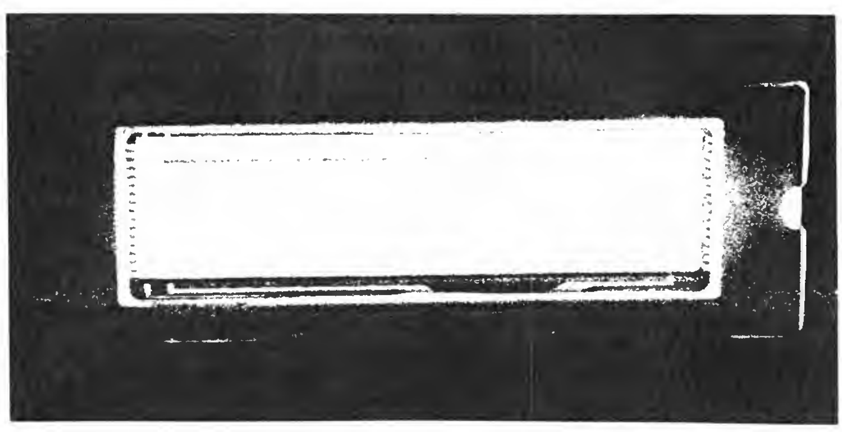
Calibration unit

In order to support the DOAS technique, one would like to have a wavelength stability of 1/100 th of a pixel. This is not achievable with a passive thermal design in such a power-limited situation. Instead, wavelength position on the detector pixels versus orbital temperature will be mapped by means of a hollow-cathode lamp (Pt-Cr-Ne) which provides a sufficient number of sharp lines in all wavelength regions.

For the radiometric calibration, the Sun will be used as the source. Because of the orbital and scanner geometry, which prevents direct viewing of the Sun via the scanning mirror, and because its high intensity would lead (even with the shortest possible integration time) to detector saturation, the Sun is viewed via a diffuser plate accommodated in the calibration unit (Fig. 9).

Previous NASA experience has shown that the diffuser is subject to degradation during its periods of exposure. Precautions are therefore taken by having:

Figure 8. Reticon RL1024SR detector chip



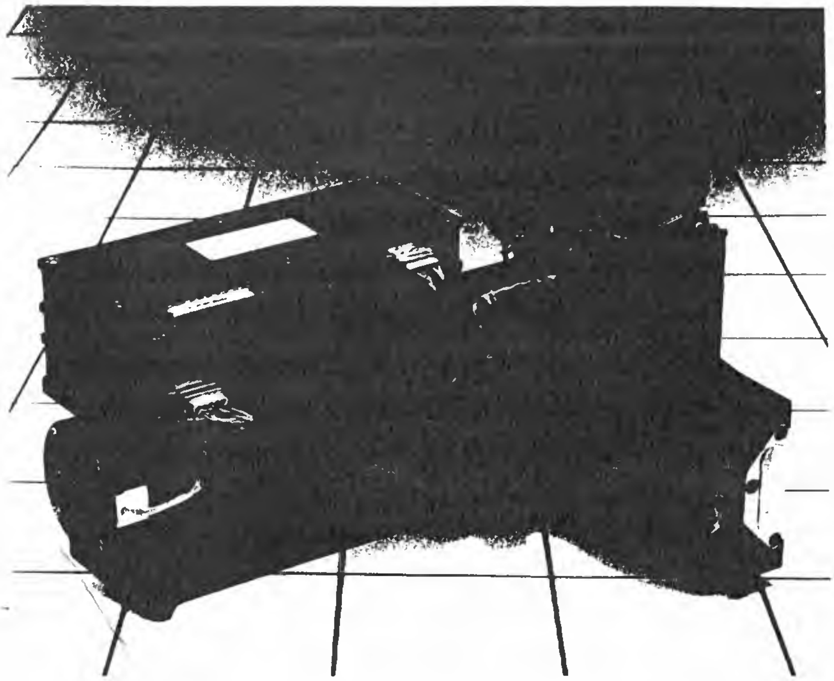


Figure 9. Calibration unit

- a mesh in front of the diffuser, attenuating the incoming light level and largely protecting the diffuser
- a shutter mechanism that opens only during Sun calibration and protects the diffuser during the remaining mission phases
- the possibility to view the calibration lamp via the diffuser, thereby having a means to monitor possible degradation, at least at those wavelengths provided by the lamp.

Scanning unit
The scanning unit consists of two separate assemblies, the Scan Mechanism (SM) and the Scan Unit Electronics Assembly (SUEA). The scan mechanism is located on the optical bench, with its rotation axis aligned with the satellite's flight direction. The axis carries a glued-on aluminium-coated mirror, which can be heated from the rear to drive off possible contaminants, if necessary.

A brushless DC motor actuates the scanner, the position of which is sensed by a resolver. The rotating part of the resolver, the mirror heater and the temperature sensor are connected to the static part via a flexible printed-circuit connection. The angular range of the scanner is limited to −63.8 to +192.2° with respect to nadir (0°) by software and end stops.

The rotation axis is supported by two spring-preloaded angular contact bearings, the balls of which are ion-plated with lead and the races are made of lead bronze. All structural parts (housing, pivot, etc.) are made from titanium.

Polarisation measurement device
The incoming light from the Earth's atmosphere can be partially polarised. Because the instrument's responses to the two orthogonal linear polarisation directions are not equal, there is a need to monitor the polarisation of the incoming light.

In the pre-disperser prism, light is internally reflected at the Brewster angle. About 5 % of this light, polarised normal to the plane of incidence, leaks away at this surface. This light is collected by an off-axis parabola, reflected by a mirror out of the plane of the optical bench, and then sensed by a custom-made photodiode array.

Because the device is not temperature-controlled, it is subject to drifts. To keep the impact of changing temperatures to a minimum, a second array of photodiodes with the same geometry, but not exposed to light, will be used to compensate for the dark current and its variability with temperature.

The measured signals are acquired by the DDHU, converted to digital signals, and included into the telemetry data (3 x 16 bit, 10.67 Hz).

Digital Data-Handling Electronics (DDHU)
The prime interface to the satellite's electrical subsystems is via the Digital Electronics Unit (DEU) of the Along-Track Scanning Radiometer (ATSR). Because the DEU now not only controls the ATSR's Infrared Radiometer (IRR) and Microwave Radiometer (MWR), but also GOME, a redundant DEU has been added, together with a DEU Switching Unit (DSU).

The DEU assumes all the normal functions of an Instrument Control Unit (ICU). Commands dedicated to GOME are expanded into a serial digital bit stream, initiating the appropriate actions within the DDHU. In the opposite direction, both housekeeping and scientific data are written by the DDHU into data buffers, from which they are requested by the DEU to be put into predefined fields of the ATSR S-band and X-band data streams.

Thermal-control hardware
The most critical aspect of the thermal control is the detector temperature, which is provided by the Peltier elements in each of the Focal-Plane Assemblies. The hot sides of the Peltiers are all connected, via copper bars and flexible connections, to a parallel pair of bent heat pipes, which end in the primary radiator exposed to deep space.

The DDHU and the scanning mirror electronics assembly have their own radiative surfaces for thermal control. The remainder of the instrument is wrapped in multi-layer insulation blankets. For cold non-operational phases, thermostat-controlled heater mats and resistors are directly powered from the payload's Power Distribution Unit.

Structure

All elements of the optics, mechanisms, electronics and thermal hardware are mounted on the optical bench, which is a nearly rectangular aluminium plate with stiffening ribs beneath. This optical bench is carried on four feet, one of which is round in cross-section and rather stiff. The other three are blade-shaped feet, with their flexing direction lying in the direction of the fixed foot. This prevents mechanical distortion of the optical alignment due to thermal expansion of the bench.

Beneath the optical bench, in the space between the ribs, the harness and the pipework for FPA evacuation are routed. An EMC shield protects the instrument from electromagnetic interference from the satellite's radars and communications system.

Operations

The GOME instrument has numerous measurement, calibration, and support modes. In particular, due to the varying light levels that will be experienced during each orbit, integration time settings will have to be adjusted frequently. In addition, once per day a Sun calibration has to be performed.

In order to limit the command traffic on the uplink, the DEU stores three different timelines, each of which can be activated automatically up to 16 times in sequence. One of these timelines is for normal operations, one for an orbit in which a Sun calibration is being performed, and one with a sidewards swath to cover the polar area (with the normal nadir-centred swath there would be a gap in coverage of about 4° around both poles).

About once per month, a wavelength mapping as function of the thermal variations will be performed with the wavelength calibration lamp. On these occasions a diffuser characterisation can also be carried out.

Lunar observations, which are restricted by the Sun–Moon–satellite scanner field-of-view geometry, will be performed whenever possible.

Data processing

GOME data will arrive together with the other 'low-bit-rate' data at the various ground stations to which the ERS tape recorders are downlinked. Extracted GOME data, together with orbit and attitude information, will then be shipped on Exabyte cassettes to the German Processing and Archiving Facility (D-PAF) in Oberpfaffenhofen. In a first processing step, the raw data will be corrected for instrument-induced errors and drifts, and provided with information on geo-location, Sun aspect angle, etc.

From these radiometrically and wavelength corrected geo-located spectra, the ozone total column amount, ozone vertical concentration profile, and data on aerosol loading and cloud cover can be retrieved. This will be done at distributed centres, according to the particular scientific expertise available. Time and budgets permitting, other atmospheric-constituent retrieval can be added to the range of data products generated. Finally, time and spatial averaging for long-term global-trend analyses is likely to be conducted (not yet specifically defined).

In addition to this off-line processing chain, some limited processing capabilities will also be installed at ESTEC, in order to evaluate the instrument performance after launch, optimise parameter settings and operating schemes, and to support possible scientific campaigns.

GOME should produce unique data as there will be no other instrument available on its time scale which duplicates its capabilities. The instrument fills a critical slot as far as future observing strategies are concerned, and GOME could well become the prototype for subsequent ozone-monitoring instruments. Its medium spectral resolution combined with a wide spectral range and absolute calibration is particularly important as it means that, in addition to applying the traditional backscatter approach, one can also use differential optical absorption spectroscopy to retrieve data with GOME.

Acknowledgements

We gratefully acknowledge the unfailing support of the GOME Science Team, headed by Prof. Dr. J. Burrows from the University of Bremen (D). Much of the work reported here has been done by the GOME Industrial Team, comprised of Officine Galileo (I), Laben (I), TPD/TNO (NL), Dornier (D) and the Rutherford Appleton Laboratory (UK), and BAe (UK) for the DEU modifications.

GOME: A New Instrument for ERS-2

A. Hahne, A. Lefebvre, J. Callies & R. Zobl
ERS Project Division, ESA Directorate for Observation of the Earth and Its Environment, ESTEC, Noordwijk, The Netherlands

The Global Ozone Monitoring Experiment, or GOME, is a new instrument that will be added to the original ERS-1 payload complement for the launch of the second European Remote-Sensing Satellite (ERS-2) in 1994. GOME is a nadir-viewing spectrometer which will observe solar radiation transmitted through or scattered from the Earth's atmosphere or from its surface. The recorded spectra will be used to derive a detailed picture of the atmosphere's content of ozone, nitrogen dioxide, water vapour, oxygen/oxygen dimer and bromine oxide and other trace gases. ERS-2's orbit will provide global Earth coverage every three days.

Introduction

In 1989, ESA decided to continue the ERS Programme beyond the expected lifetime of the ERS-1 satellite by approving the building and launch of the ERS-2 satellite. To provide the necessary continuity to the observations started by the instruments of ERS-1, ERS-2 is essentially a carbon-copy of the ERS-1 satellite. It was recognised, however, that there is an urgent need to investigate the composition and dynamic behaviour of the Earth's atmosphere. The ERS-2 Programme approval therefore included an experimental sensor for atmospheric research, the 'Global Ozone Monitoring Experiment' (GOME), which is essentially a scaled-down version of the SCIAMACHY instrument proposed for the European Polar Platform to be launched at the end of the century.

The inclusion of the GOME sensor in ERS-2 Programme was endorsed on the explicit understanding that:

- the sensor would be developed, tested, calibrated and integrated in the same time frame as the satellite and the other instruments would be rebuilt
- the resource demands of the sensor would have to be satisfied from the existing system margins, imposing stringent limitations on mass, power and data rate
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The limitations on resources have already led to drastic changes in the instrument concept, because at the Baseline Design Review held in February 1991 it became obvious that the power/energy demand exceeded the available margin. Instead of GOME having its own interface to the On-Board Computer (OBC) and to the Instrument Data Handling and Transmission (IDHT) system, it was decided to provide these functions via the existing interfaces of the Along-Track Scanning Radiometer (ATSR) instrument.

Scientific objectives

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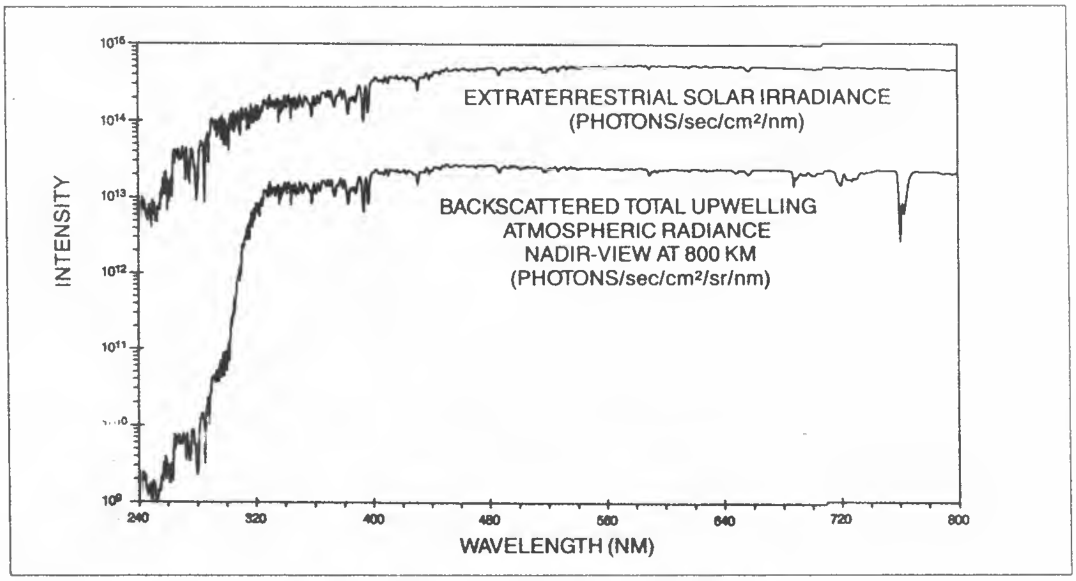

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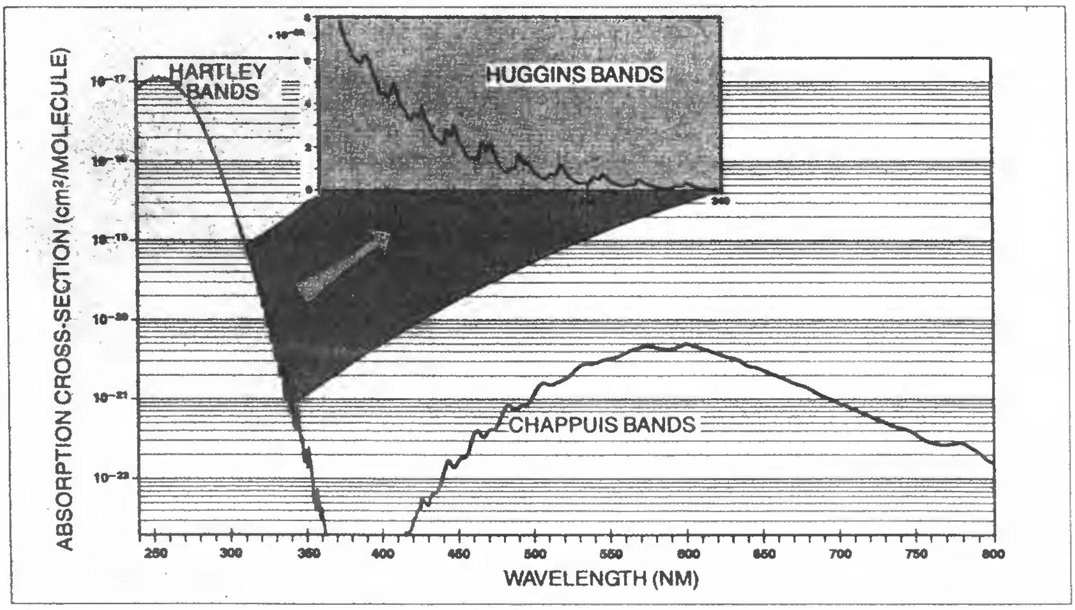

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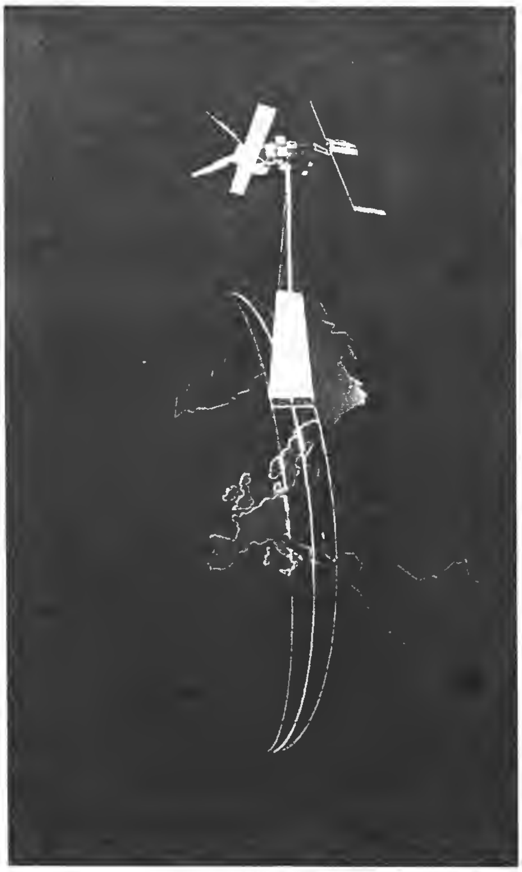

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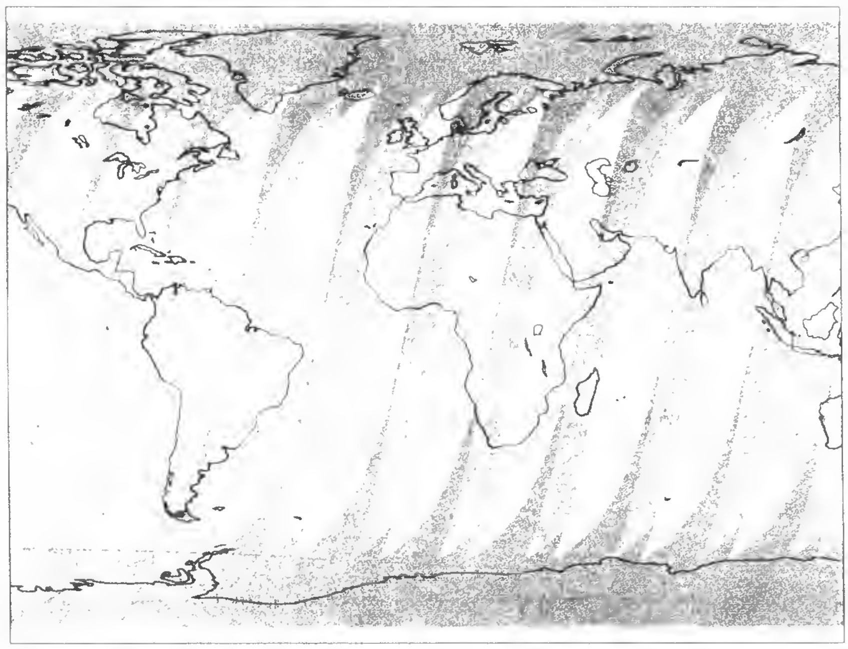

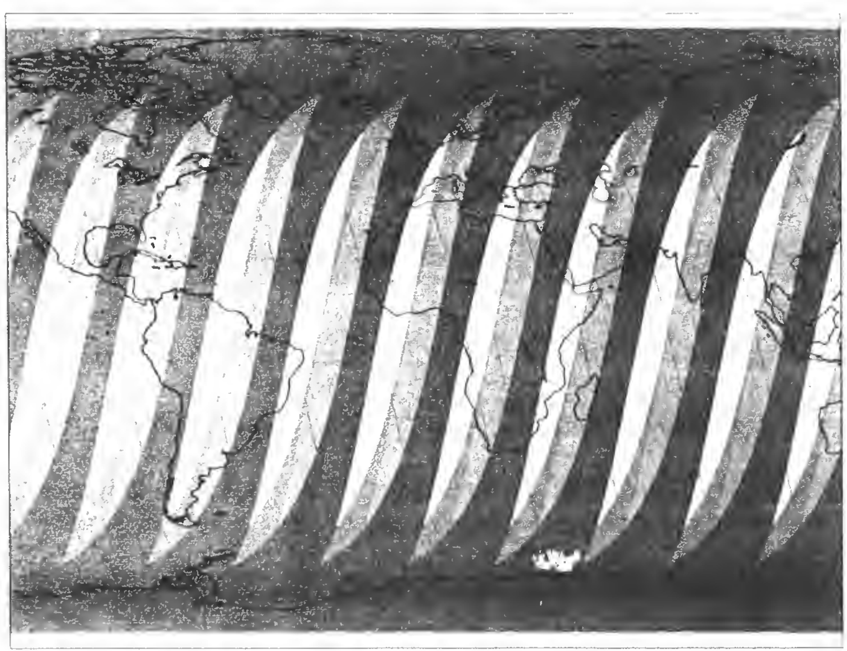

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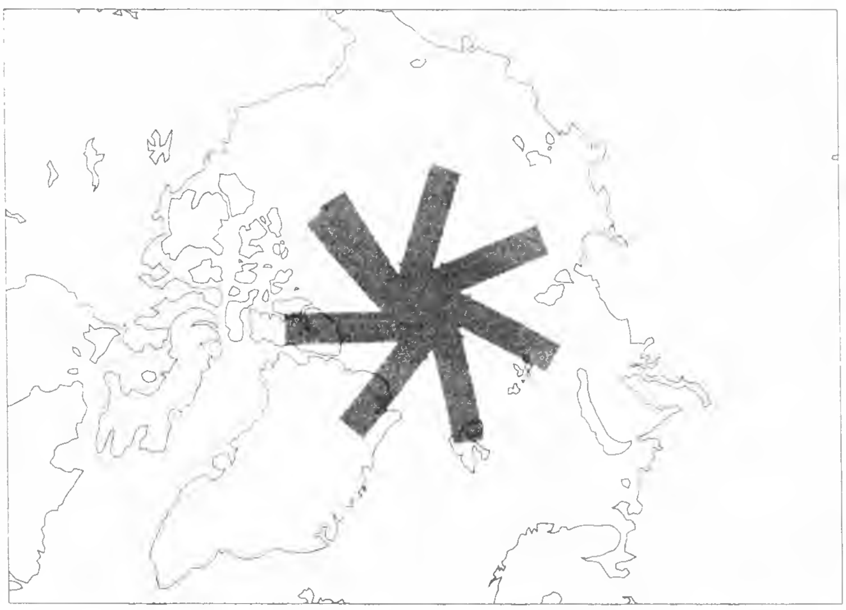

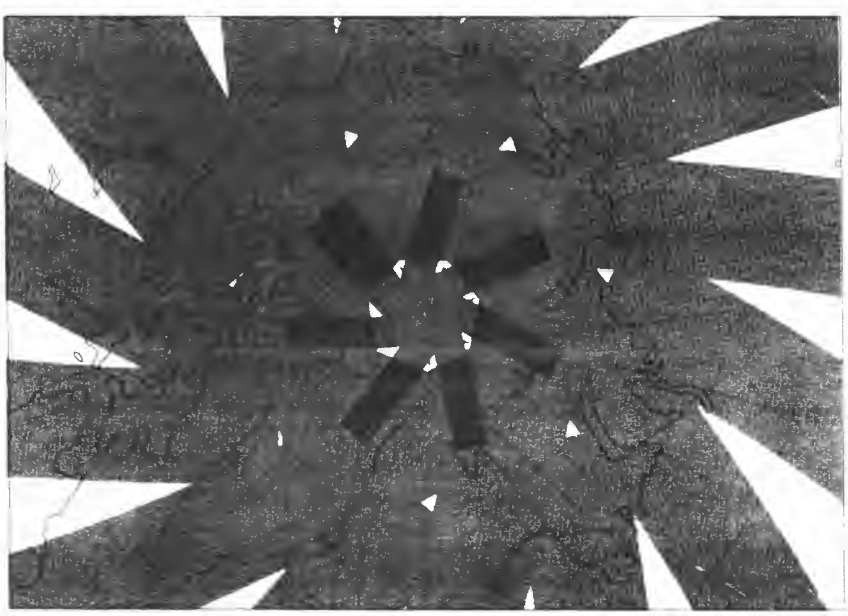

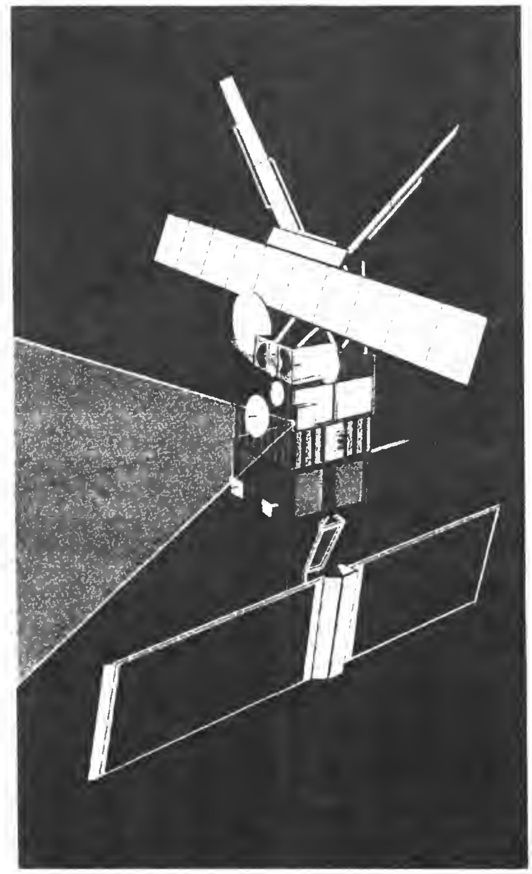

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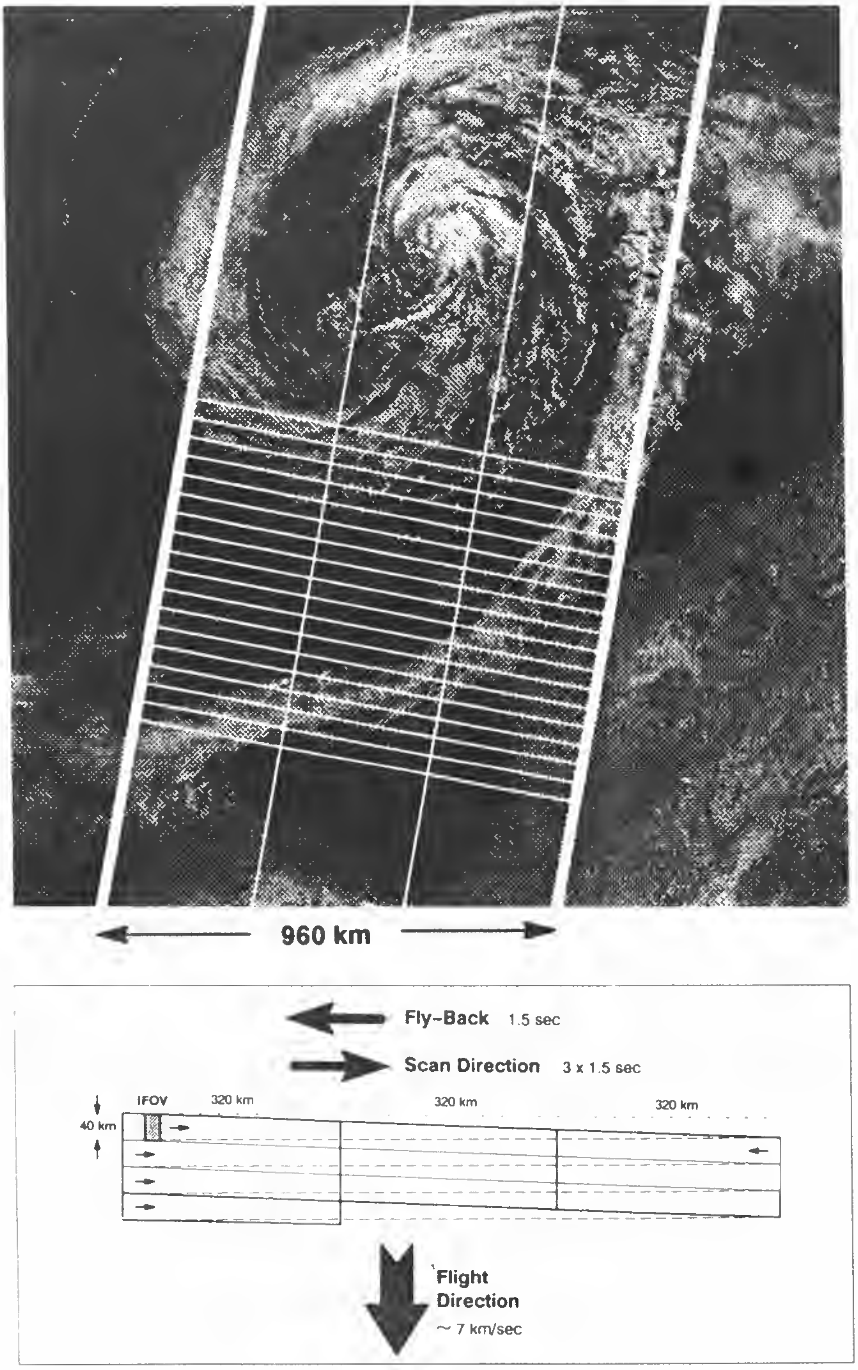

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Spectrometer optics

In the spectrometer optics, shown schematically in Figure 7, the light reflected off the scanning mirror is focussed by an anamorphic telescope such that the shape of the focus matches the entrance slit of the spectrometer (dimensions 10 mm x 100 µm. After the slit, the light is collimated by an off-axis parabolic mirror. It then strikes the quartz pre-disperser prism, causing a moderately wavelength dispersed beam. Another prism acts as channel separator: the upper edge of this prism reaches into the wavelength-dispersed beam, letting the longer wavelengths pass, reflecting the wavelength range 290–405 nm into Channel 2 by means of a dielectric reflecting coating, and guiding the wavelength range 240–295 nm internal to the prism into Channel 1. The unaffected wavelength range of 405–790 nm is then split up by a dichroic beam splitter into Channels 3 (400–605 nm) and 4 (590–790 nm).

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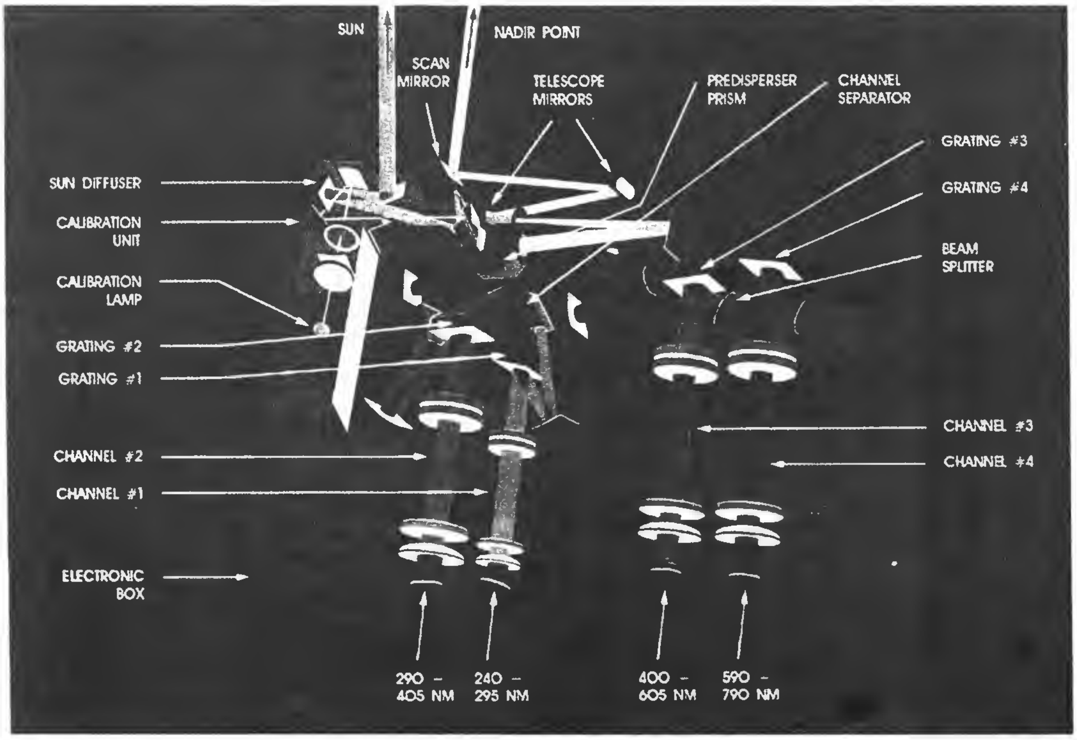

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bands, the integration times of which may be varied individually. The Reticon detector chip is shown in Figure 8. The detectors are glued onto two-stage Peltier coolers, which reduce their temperature to −40°C to keep the dark current of the photodiodes sufficiently low. The hot side of the Peltier coolers is glued (in the engineering model), respectively brazed (in the flight model), to a copper bar, extending through the pin-plate. Outside the FPA, this copper bar is connected via flexible connections and heat pipes to the main radiator. The tips carrying the Peltier coolers and detectors are tilted between 1.6° and 9.5°, to compensate for chromatic aberration.

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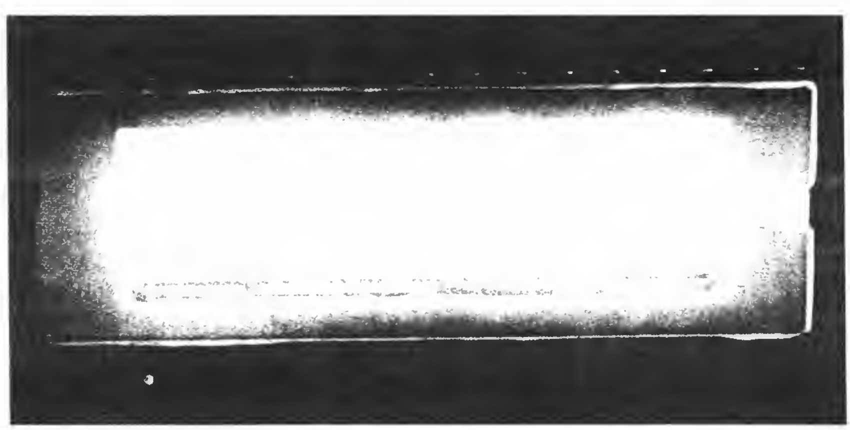
Previous NASA experience has shown that the diffuser is subject to degradation during its periods of exposure. Precautions are therefore taken by having:

Figure 8. Reticon RL1024SR detector chip



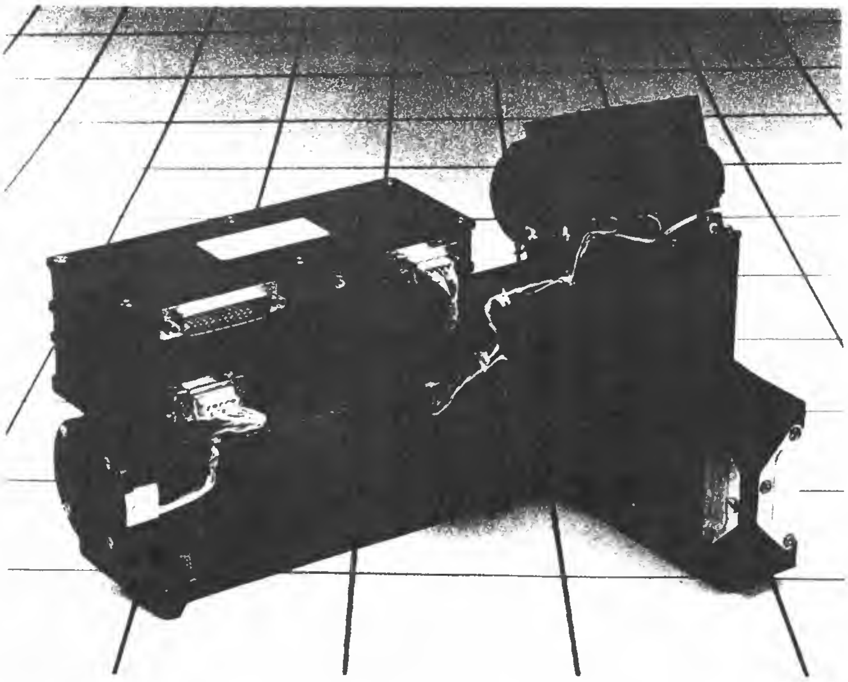


Figure 9. Calibration unit

- a mesh in front of the diffuser, attenuating the incoming light level and largely protecting the diffuser
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A brushless DC motor actuates the scanner, the position of which is sensed by a resolver. The rotating part of the resolver, the mirror heater and the temperature sensor are connected to the static part via a flexible printed-circuit connection. The angular range of the scanner is limited to −63.8 to +192.2° with respect to nadir (0°) by software and end stops.

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The incoming light from the Earth's atmosphere can be partially polarised. Because the instrument's responses to the two orthogonal linear polarisation directions are not equal, there is a need to monitor the polarisation of the incoming light.

In the pre-disperser prism, light is internally reflected at the Brewster angle. About 5 % of this light, polarised normal to the plane of incidence, leaks away at this surface. This light is collected by an off-axis parabola, reflected by a mirror out of the plane of the optical bench, and then sensed by a custom-made photodiode array.

Because the device is not temperature-controlled, it is subject to drifts. To keep the impact of changing temperatures to a minimum, a second array of photodiodes with the same geometry, but not exposed to light, will be used to compensate for the dark current and its variability with temperature.

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The prime interface to the satellite's electrical subsystems is via the Digital Electronics Unit (DEU) of the Along-Track Scanning Radiometer (ATSR). Because the DEU now not only controls the ATSR's Infrared Radiometer (IRR) and Microwave Radiometer (MWR), but also GOME, a redundant DEU has been added, together with a DEU Switching Unit (DSU).

The DEU assumes all the normal functions of an Instrument Control Unit (ICU). Commands dedicated to GOME are expanded into a serial digital bit stream, initiating the appropriate actions within the DDHU. In the opposite direction, both housekeeping and scientific data are written by the DDHU into data buffers, from which they are requested by the DEU to be put into predefined fields of the ATSR S-band and X-band data streams.

Thermal-control hardware
The most critical aspect of the thermal control is the detector temperature, which is provided by the Peltier elements in each of the Focal-Plane Assemblies. The hot sides of the Peltiers are all connected, via copper bars and flexible connections, to a parallel pair of bent heat pipes, which end in the primary radiator exposed to deep space.

The DDHU and the scanning mirror electronics assembly have their own radiative surfaces for thermal control. The remainder of the instrument is wrapped in multi-layer insulation blankets. For cold non-operational phases, thermostat-controlled heater mats and resistors are directly powered from the payload's Power Distribution Unit.

Structure

All elements of the optics, mechanisms, electronics and thermal hardware are mounted on the optical bench, which is a nearly rectangular aluminium plate with stiffening ribs beneath. This optical bench is carried on four feet, one of which is round in cross-section and rather stiff. The other three are blade-shaped feet, with their flexing direction lying in the direction of the fixed foot. This prevents mechanical distortion of the optical alignment due to thermal expansion of the bench.

Beneath the optical bench, in the space between the ribs, the harness and the pipework for FPA evacuation are routed. An EMC shield protects the instrument from electromagnetic interference from the satellite's radars and communications system.

Operations

The GOME instrument has numerous measurement, calibration, and support modes. In particular, due to the varying light levels that will be experienced during each orbit, integration time settings will have to be adjusted frequently. In addition, once per day a Sun calibration has to be performed.

In order to limit the command traffic on the uplink, the DEU stores three different timelines, each of which can be activated automatically up to 16 times in sequence. One of these timelines is for normal operations, one for an orbit in which a Sun calibration is being performed, and one with a sidewards swath to cover the polar area (with the normal nadir-centred swath there would be a gap in coverage of about 4° around both poles).

About once per month, a wavelength mapping as function of the thermal variations will be performed with the wavelength calibration lamp. On these occasions a diffuser characterisation can also be carried out.

Lunar observations, which are restricted by the Sun–Moon–satellite scanner field-of-view geometry, will be performed whenever possible.

Data processing

GOME data will arrive together with the other 'low-bit-rate' data at the various ground stations to which the ERS tape recorders are downlinked. Extracted GOME data, together with orbit and attitude information, will then be shipped on Exabyte cassettes to the German Processing and Archiving Facility (D-PAF) in Oberpfaffenhofen. In a first processing step, the raw data will be corrected for instrument-induced errors and drifts, and provided with information on geo-location, Sun aspect angle, etc.

From these radiometrically and wavelength corrected geo-located spectra, the ozone total column amount, ozone vertical concentration profile, and data on aerosol loading and cloud cover can be retrieved. This will be done at distributed centres, according to the particular scientific expertise available. Time and budgets permitting, other atmospheric-constituent retrieval can be added to the range of data products generated. Finally, time and spatial averaging for long-term global-trend analyses is likely to be conducted (not yet specifically defined).

In addition to this off-line processing chain, some limited processing capabilities will also be installed at ESTEC, in order to evaluate the instrument performance after launch, optimise parameter settings and operating schemes, and to support possible scientific campaigns.

GOME should produce unique data as there will be no other instrument available on its time scale which duplicates its capabilities. The instrument fills a critical slot as far as future observing strategies are concerned, and GOME could well become the prototype for subsequent ozone-monitoring instruments. Its medium spectral resolution combined with a wide spectral range and absolute calibration is particularly important as it means that, in addition to applying the traditional backscatter approach, one can also use differential optical absorption spectroscopy to retrieve data with GOME.

Acknowledgements

We gratefully acknowledge the unfailing support of the GOME Science Team, headed by Prof. Dr. J. Burrows from the University of Bremen (D). Much of the work reported here has been done by the GOME Industrial Team, comprised of Officine Galileo (I), Laben (I), TPD/TNO (NL), Dornier (D) and the Rutherford Appleton Laboratory (UK), and BAe (UK) for the DEU modifications.

GOME: A New Instrument for ERS-2

A. Hahne, A. Lefebvre, J. Callies & R. Zobl
ERS Project Division, ESA Directorate for Observation of the Earth and Its Environment, ESTEC, Noordwijk, The Netherlands

The Global Ozone Monitoring Experiment, or GOME, is a new instrument that will be added to the original ERS-1 payload complement for the launch of the second European Remote-Sensing Satellite (ERS-2) in 1994. GOME is a nadir-viewing spectrometer which will observe solar radiation transmitted through or scattered from the Earth's atmosphere or from its surface. The recorded spectra will be used to derive a detailed picture of the atmosphere's content of ozone, nitrogen dioxide, water vapour, oxygen/oxygen dimer and bromine oxide and other trace gases. ERS-2's orbit will provide global Earth coverage every three days.

Introduction

In 1989, ESA decided to continue the ERS Programme beyond the expected lifetime of the ERS-1 satellite by approving the building and launch of the ERS-2 satellite. To provide the necessary continuity to the observations started by the instruments of ERS-1, ERS-2 is essentially a carbon-copy of the ERS-1 satellite. It was recognised, however, that there is an urgent need to investigate the composition and dynamic behaviour of the Earth's atmosphere. The ERS-2 Programme approval therefore included an experimental sensor for atmospheric research, the 'Global Ozone Monitoring Experiment' (GOME), which is essentially a scaled-down version of the SCIAMACHY instrument proposed for the European Polar Platform to be launched at the end of the century.

The inclusion of the GOME sensor in ERS-2 Programme was endorsed on the explicit understanding that:
- the sensor would be developed, tested, calibrated and integrated in the same time frame as the satellite and the other instruments would be rebuilt
- the resource demands of the sensor would have to be satisfied from the existing system margins, imposing stringent limitations on mass, power and data rate
- no major upgrades in the ERS Ground Segment would be needed, and the financial burden for the data-processing algorithms and software would be borne by scientific institutions and/or national agencies.

The limitations on resources have already led to drastic changes in the instrument concept, because at the Baseline Design Review held in February 1991 it became obvious that the power/energy demand exceeded the available margin. Instead of GOME having its own interface to the On-Board Computer (OBC) and to the Instrument Data Handling and Transmission (IDHT) system, it was decided to provide these functions via the existing interfaces of the Along-Track Scanning Radiometer (ATSR) instrument.

Scientific objectives

Ozone (O_3) is a tri-atomic form of oxygen, formed by hard ultraviolet radiation in the atmospheric layer between about 15 and 45 km altitude, the so-called 'stratosphere'. It absorbs radiation in the spectral region between 240 and 310 nm, preventing these harmful rays from reaching the ground in large quantities. This naturally protective atmospheric layer is now being threatened by human activities, in particular by the steady release of chlorfluorocarbons (CFCs) into the atmosphere. The accumulated anthropogenic effects on stratospheric ozone are believed to be causing a steady depletion of the ozone layer by approximately 0.3 % per year.

The chemistry of the stratosphere is very complex. The hard ultraviolet radiation causes the breakup of many of the available species into reactive fragments, which lead to a multitude of possible reactions. Normally, the rates of these reactions depend not only on the nature of the species, but also on local pressure, temperature, radiative fluxes in the different wavelength regions, vertical and horizontal transport processes, etc. Thus, in order to understand the ozone chemistry fully, it is not sufficient just to measure the ozone; one must also monitor the abundances of many other species, including very

reactive intermediate species occurring in only very low concentrations.

Reflecting this need, GOME is intended to measure other species as well as to observe aerosols and polar stratospheric clouds which play significant roles in the heterogeneous processes associated with ozone chemistry. It is hoped that some of these species may be observed in the troposphere, another part of the atmosphere believed to be affected by man's activities. However, the presence of clouds may make this difficult.

For this GOME will exploit spectroscopy, which is a viable technique for observing trace species in the atmosphere. Sunlight, reflected by the ground surface and scattered within the different atmospheric layers, carries the absorption signatures of the absorbing species (Figs. 1 & 2). The GOME instrument is designed to collect this light over the entire wavelength region from 240 to 790 nm, in which not only ozone, but also a number of other atmospheric species absorb. In addition to the classical backscatter technique, the GOME instrument exploits the novel technique of 'Differential Absorption Spectroscopy' (DOAS)*.

Satellite mission and instrument accommodation

Like its predecessor ERS-1, ERS-2 will fly in a Sun-synchronous polar orbit with an inclination of 98°, with a mean altitude of 780 km and a local time of 10.30 h for the equator crossing on the descending node. This results in an orbital period of approximately 100 min and a ground speed for the subsatellite point of 7 km/s.

The GOME instrument's instantaneous field of view has been chosen to be 40 km x 2 km, or 2.8° x 0.14°. Via the

* Developed by U. Platt (Heidelberg, FRG)

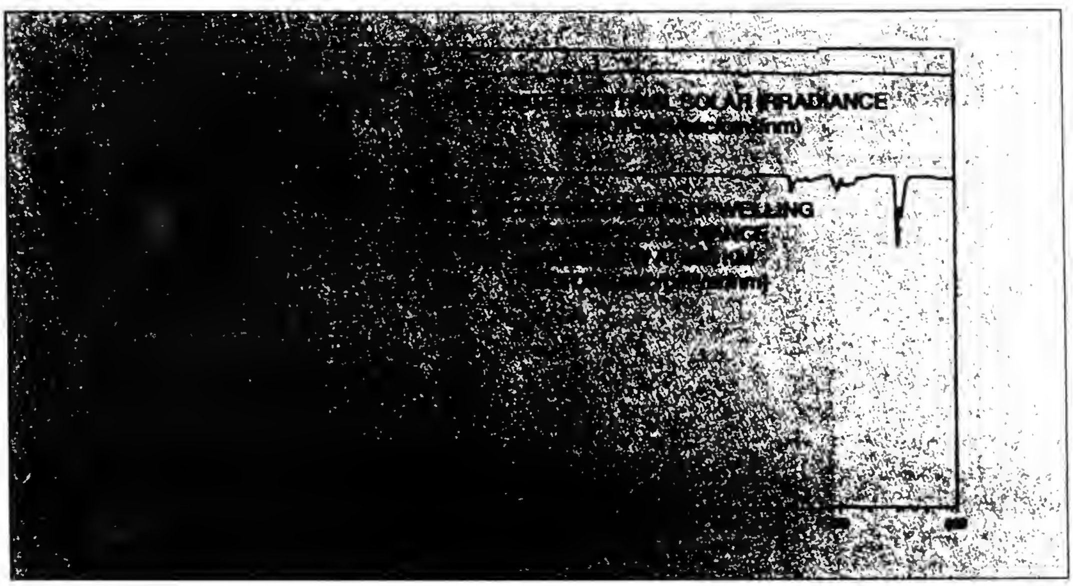


Figure 1. LOWTRAN simulation of spectral radiances at the top of the atmosphere in the wavelength range of the GOME instrument, i.e. 240–790 nm

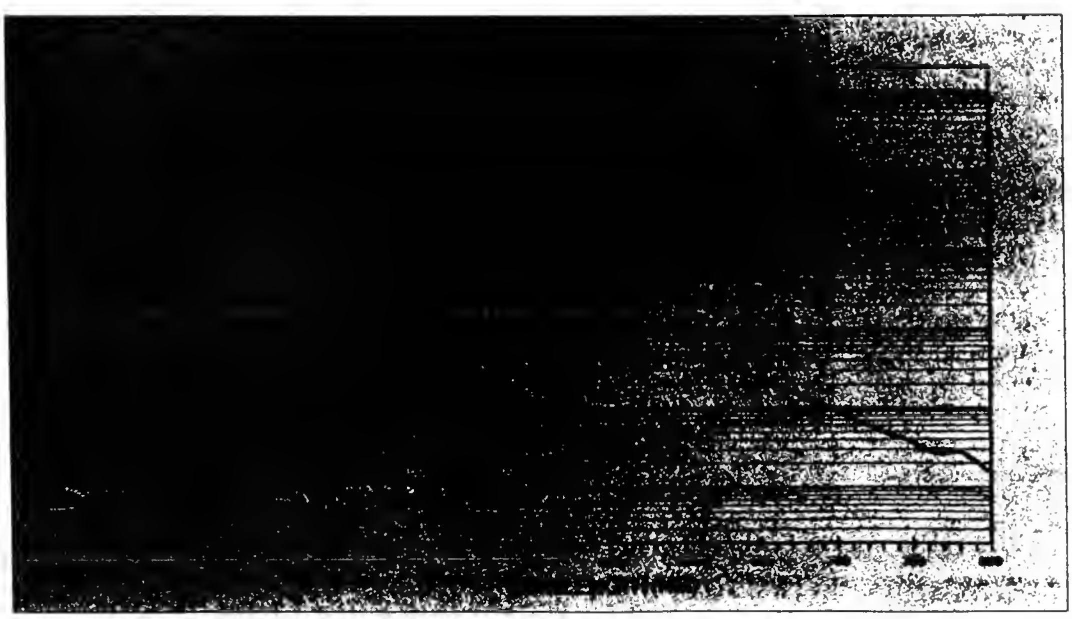


Figure 2. Ozone absorption cross-sections in the wavelength range of the GOME instrument

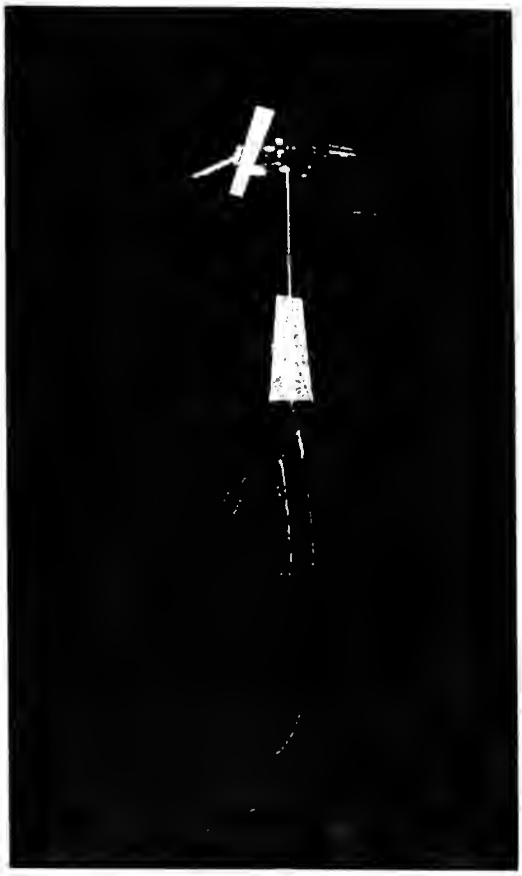


Figure 3. Artist's impression of the GOME instrument's scanning geometry

movement of the instrument's scanning mirror, this instantaneous field of view can be scanned across the satellite's track. With a ±31° scan, global coverage can be achieved within 3 days, except for a gap of approximately 4° around both poles. To overcome this limitation, a special pole-viewing mode has been included (Figs. 3 & 4a,b).

The GOME instrument is mounted externally, on the surface of the payload module facing in the flight direction (i.e. the −Y face), with a clear field of view in the nadir direction (Fig. 5). It is thermally decoupled from the spacecraft structure as far as possible.

Photon flux computations show that for the visible/near-infrared channels, a good signal-to-noise ratio can be achieved with a 1.5 s integration time on the detector. The time for one forward scan has therefore been set to 4.5 s. For the flyback of the scanning mirror, another 1.5 s have been allowed, resulting in the scan pattern shown in Figure 6, with a ground pixel size of 320 km x 40 km.

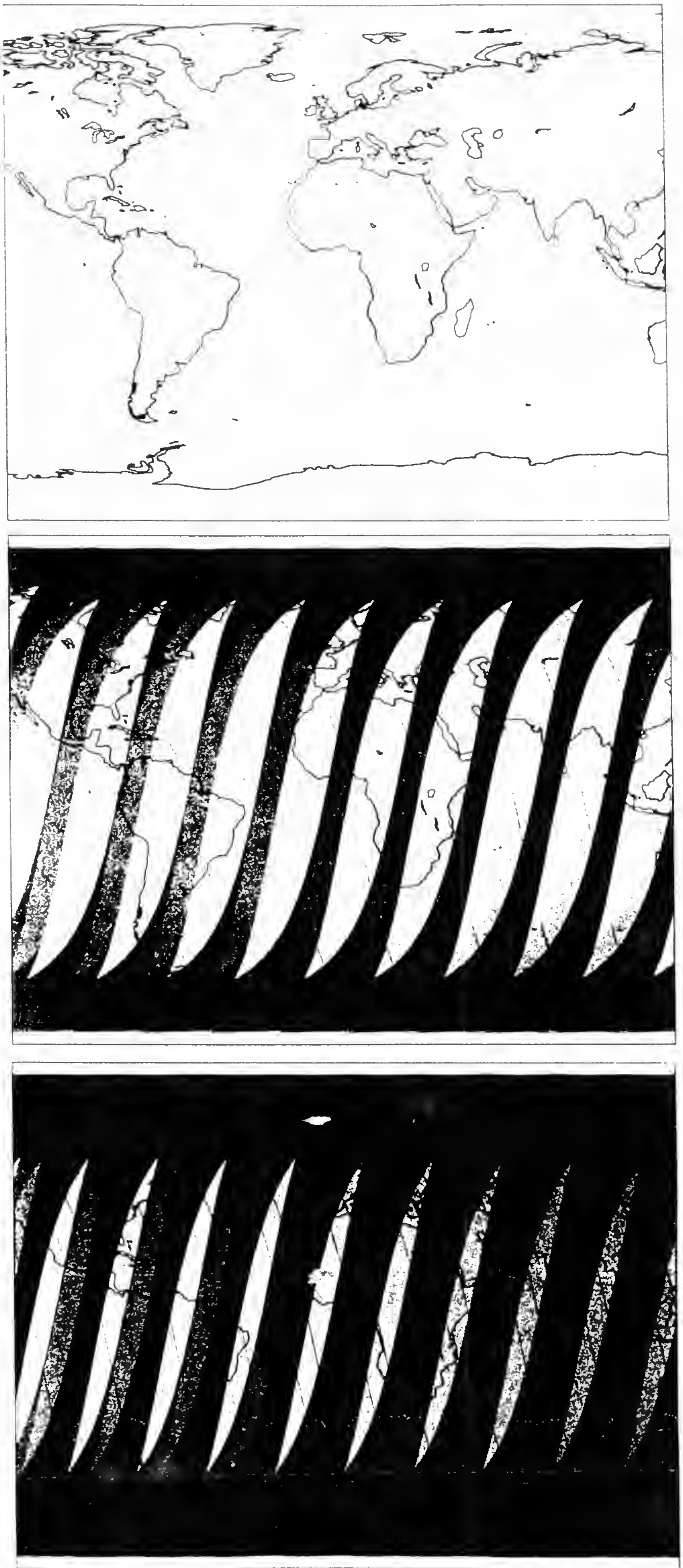
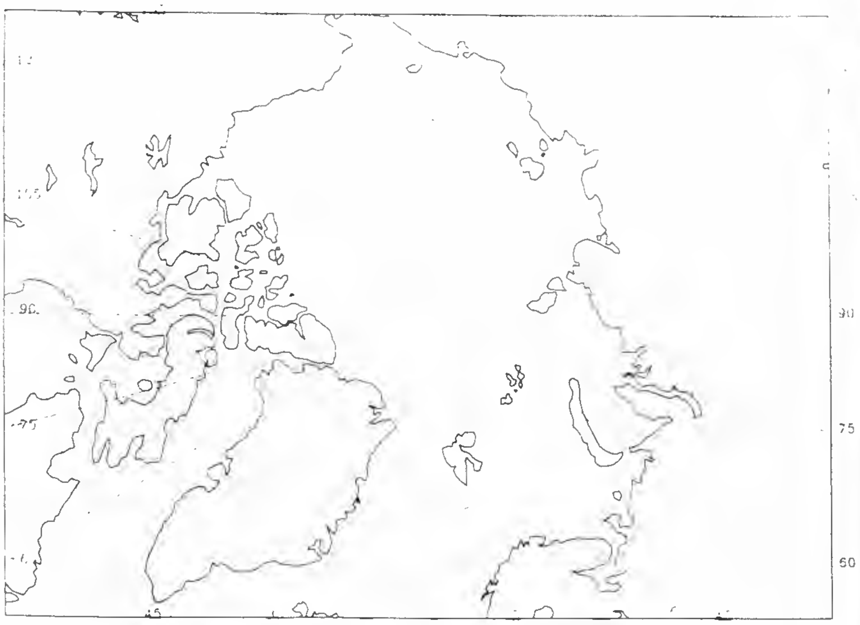
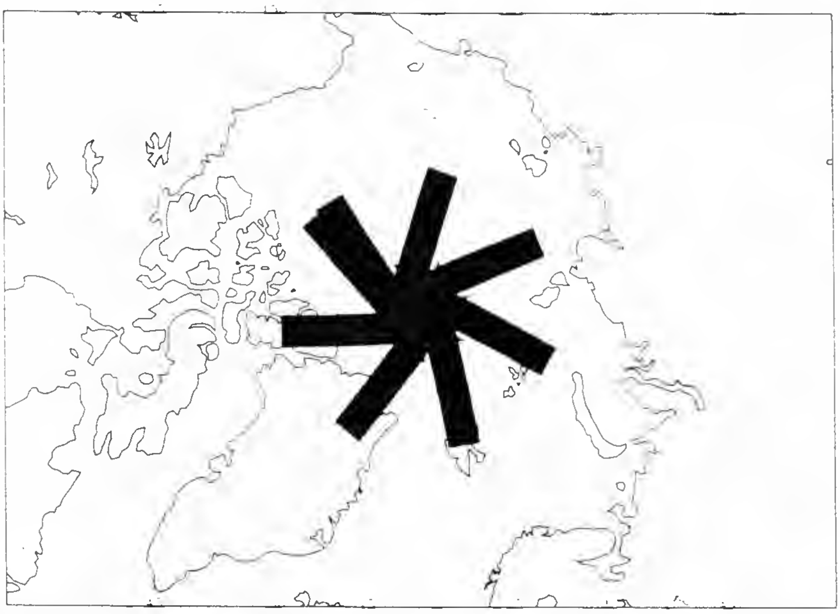


Figure 4a. Three-day coverage map for GOME





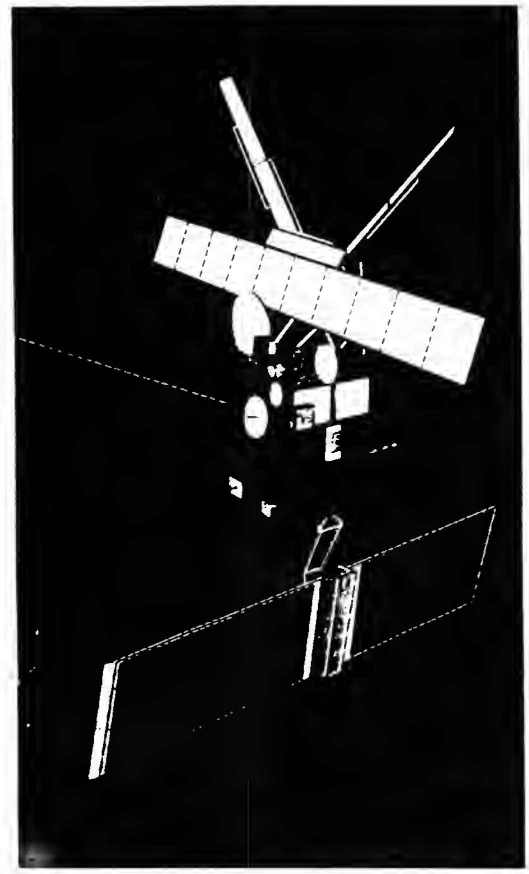


Figure 5. Artist's impression of the GOME instrument aboard ERS-2

The instrument's design

As a general principle, the GOME instrument collects light arriving from the Sun-illuminated Earth's atmosphere and decomposes it into its spectral components. In order to provide both the required spectral coverage from 240 to 790 nm and a good spectral resolution of 0.2–0.4 nm, this decomposition is done in two steps: first by a quartz pre-disperser prism, in which the light is split into four different channels. Each of these channels contains a grating as second dispersing element, and a 1024-pixel silicon array detector (the integration times on the chip can be multiples of 93.75 ms, with 1.5 s for the visible and 30 s for the ultraviolet being the default values)

The entire GOME instrument can be broken down into the following functional blocks:
- the spectrometer
- the four Focal-Plane Assemblies (FPAs)
- the Calibration Unit
- the scan unit with the scanning mechanism and the scan unit electronics (SEU) assembly

Figure 4b. Three-day coverage map for GOME

- the Polarisation Measurement Device (PMD)
- the Digital Data Handling Unit (DDHU)
- the optical bench structure
- the thermal control hardware.

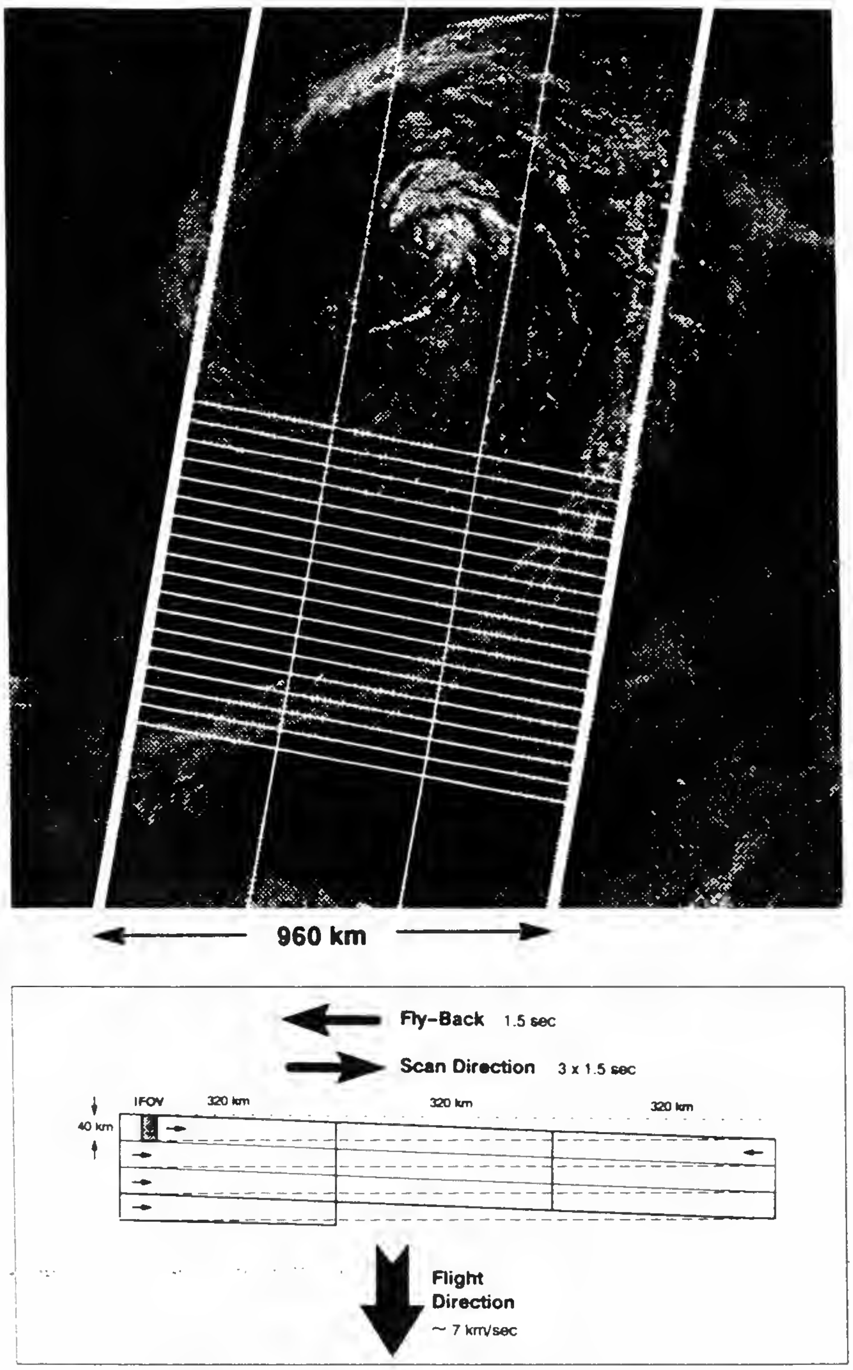


Figure 6. GOME scan pattern (graphic courtesy of DLR, Oberpfaffenhofen)

Table 1. Key optics performance parameters

Band	Wavelength range (nm)	Grating (l/mm)	Pixel resolution (nm)	Spectral resolution (nm)
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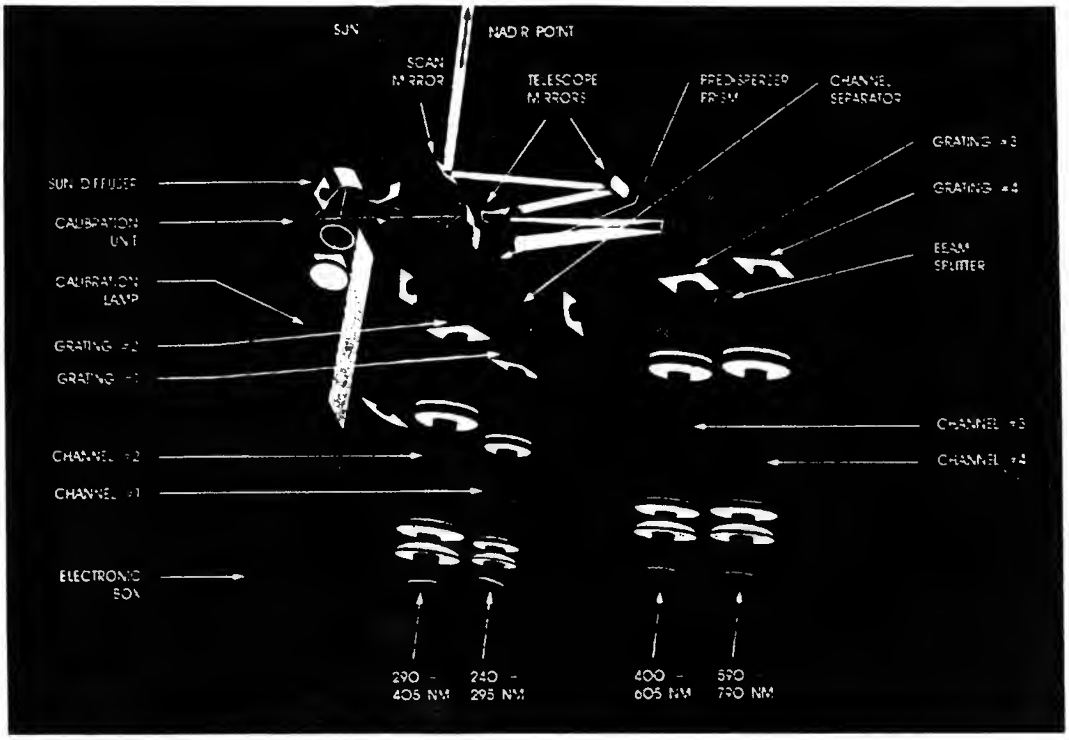

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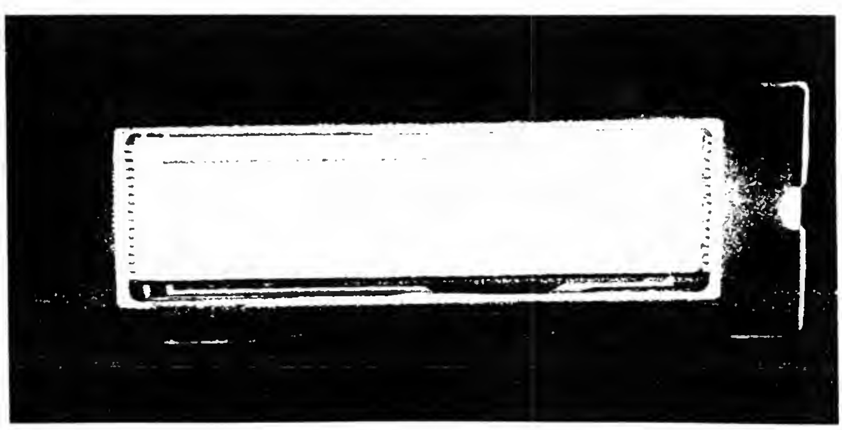
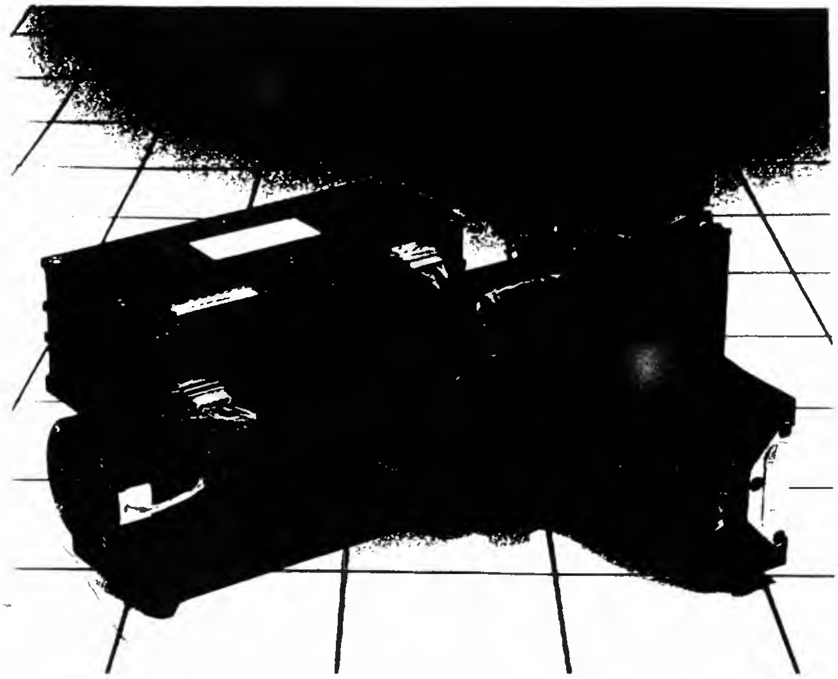
Figure 8. Reticon RL1024SR detector chip





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GOME: A New Instrument for ERS-2

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The Global Ozone Monitoring Experiment, or GOME, is a new instrument that will be added to the original ERS-1 payload complement for the launch of the second European Remote-Sensing Satellite (ERS-2) in 1994. GOME is a nadir-viewing spectrometer which will observe solar radiation transmitted through or scattered from the Earth's atmosphere or from its surface. The recorded spectra will be used to derive a detailed picture of the atmosphere's content of ozone, nitrogen dioxide, water vapour, oxygen/oxygen dimer and bromine oxide and other trace gases. ERS-2's orbit will provide global Earth coverage every three days.

Introduction

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The inclusion of the GOME sensor in ERS-2 Programme was endorsed on the explicit understanding that:
- the sensor would be developed, tested, calibrated and integrated in the same time frame as the satellite and the other instruments would be rebuilt
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The limitations on resources have already led to drastic changes in the instrument concept, because at the Baseline Design Review held in February 1991 it became obvious that the power/energy demand exceeded the available margin. Instead of GOME having its own interface to the On-Board Computer (OBC) and to the Instrument Data Handling and Transmission (IDHT) system, it was decided to provide these functions via the existing interfaces of the Along-Track Scanning Radiometer (ATSR) instrument.

Scientific objectives

Ozone (O_3) is a tri-atomic form of oxygen, formed by hard ultraviolet radiation in the atmospheric layer between about 15 and 45 km altitude, the so-called 'stratosphere'. It absorbs radiation in the spectral region between 240 and 310 nm, preventing these harmful rays from reaching the ground in large quantities. This naturally protective atmospheric layer is now being threatened by human activities, in particular by the steady release of chlorfluorocarbons (CFCs) into the atmosphere. The accumulated anthropogenic effects on stratospheric ozone are believed to be causing a steady depletion of the ozone layer by approximately 0.3 % per year.

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Like its predecessor ERS-1, ERS-2 will fly in a Sun-synchronous polar orbit with an inclination of 98°, with a mean altitude of 780 km and a local time of 10.30 h for the equator crossing on the descending node. This results in an orbital period of approximately 100 min and a ground speed for the subsatellite point of 7 km/s.

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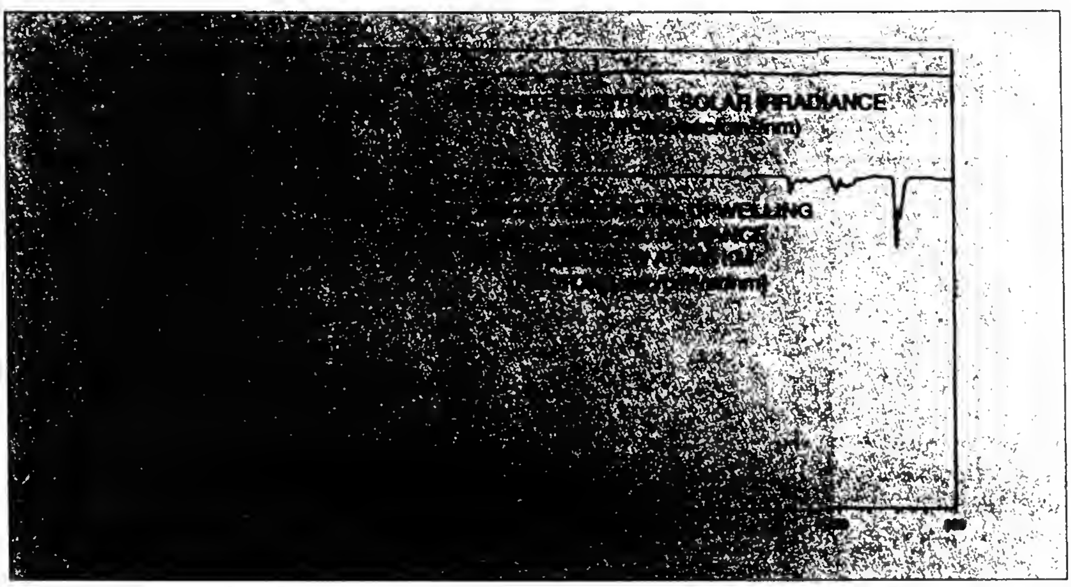


Figure 1. LOWTRAN simulation of spectral radiances at the top of the atmosphere in the wavelength range of the GOME instrument, i.e. 240–790 nm

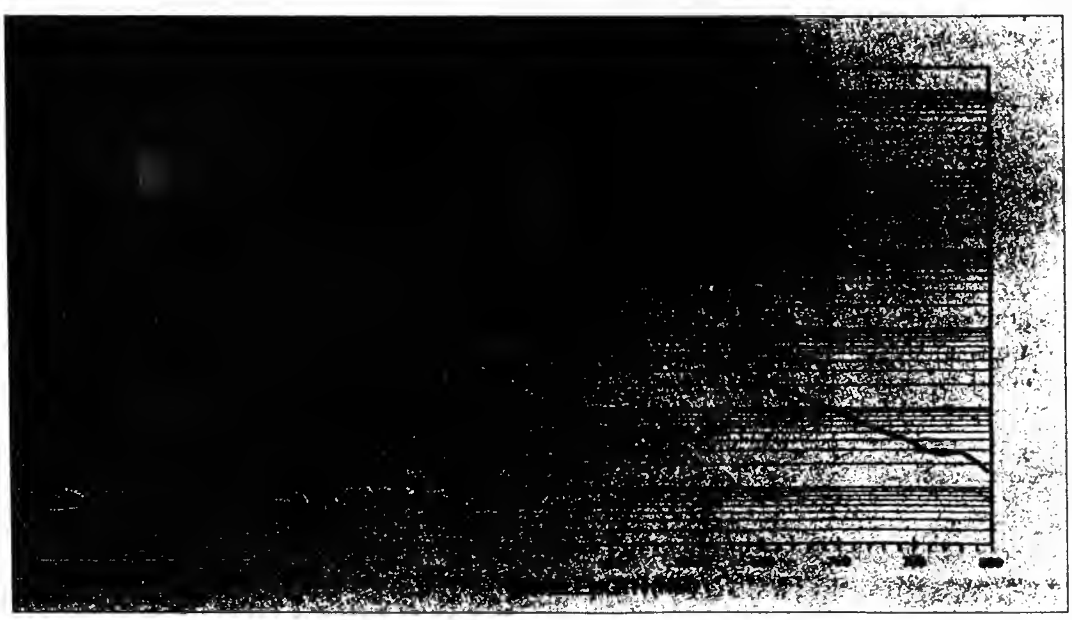


Figure 2. Ozone absorption cross-sections in the wavelength range of the GOME instrument

Figure 3. Artist's impression of the GOME instrument's scanning geometry

movement of the instrument's scanning mirror, this instantaneous field of view can be scanned across the satellite's track. With a ±31° scan, global coverage can be achieved within 3 days, except for a gap of approximately 4° around both poles. To overcome this limitation, a special pole-viewing mode has been included (Figs. 3 & 4a,b)

The GOME instrument is mounted externally, on the surface of the payload module facing in the flight direction (i.e. the –Y face), with a clear field of view in the nadir direction (Fig. 5). It is thermally decoupled from the spacecraft structure as far as possible.

Photon flux computations show that for the visible/near-infrared channels, a good signal-to-noise ratio can be achieved with a 1.5 s integration time on the detector. The time for one forward scan has therefore been set to 4.5 s. For the flyback of the scanning mirror, another 1.5 s have been allowed, resulting in the scan pattern shown in Figure 6, with a ground pixel size of 320 km x 40 km

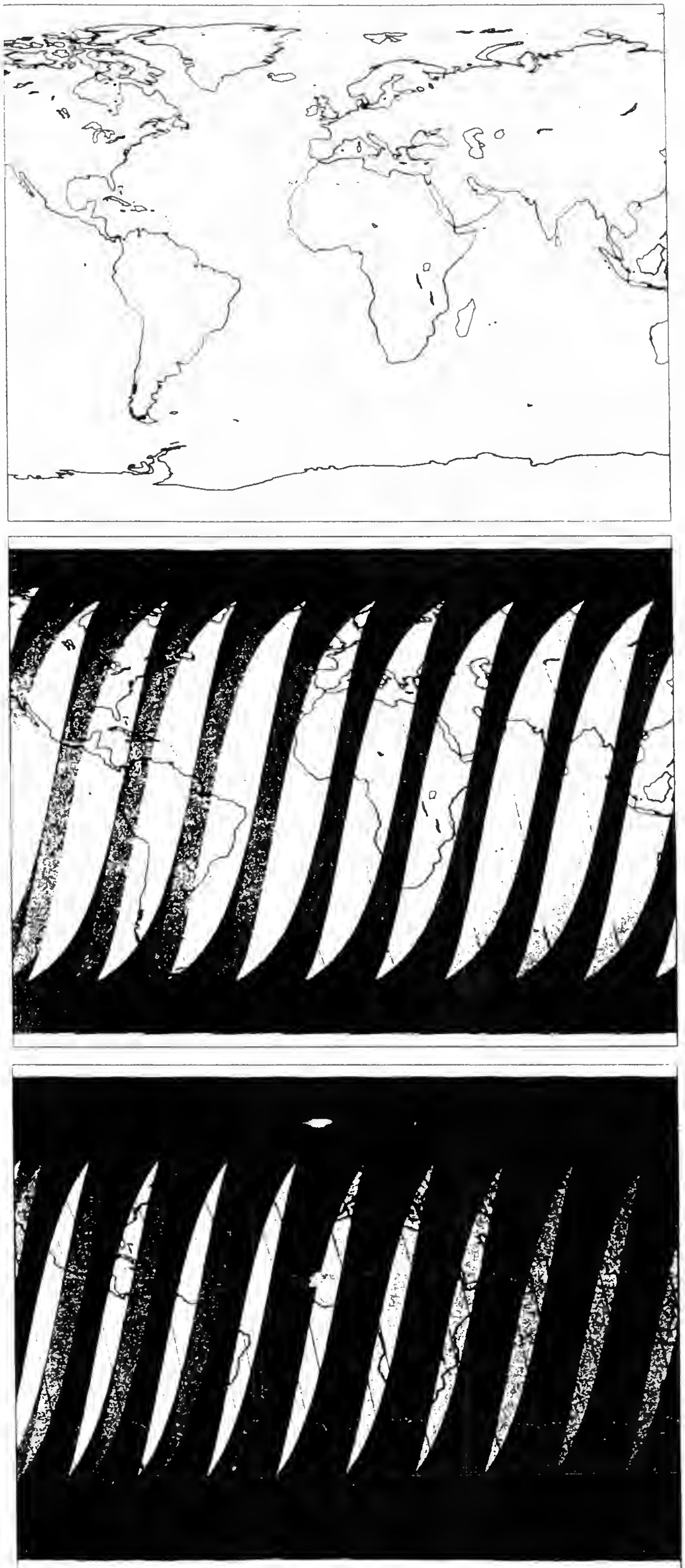
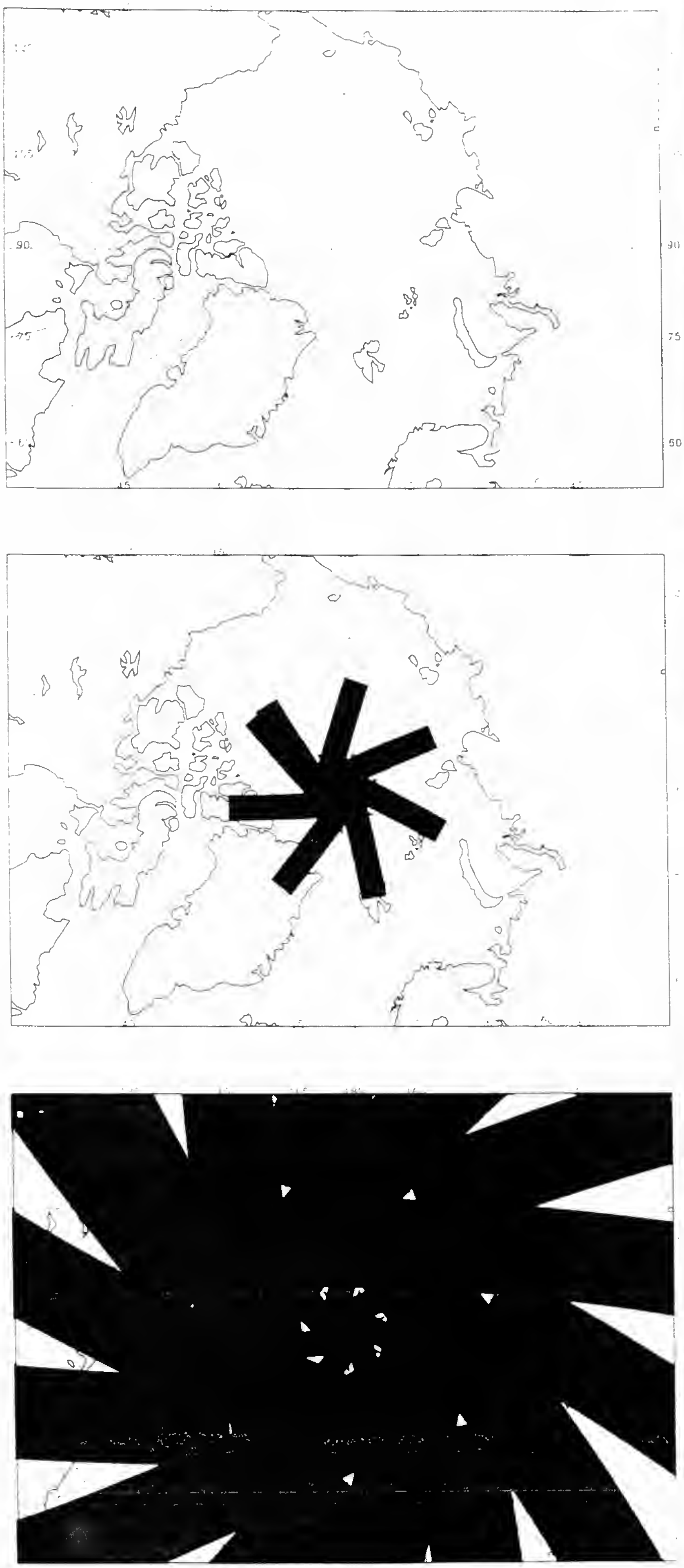


Figure 4a. Three-day coverage map for GOME



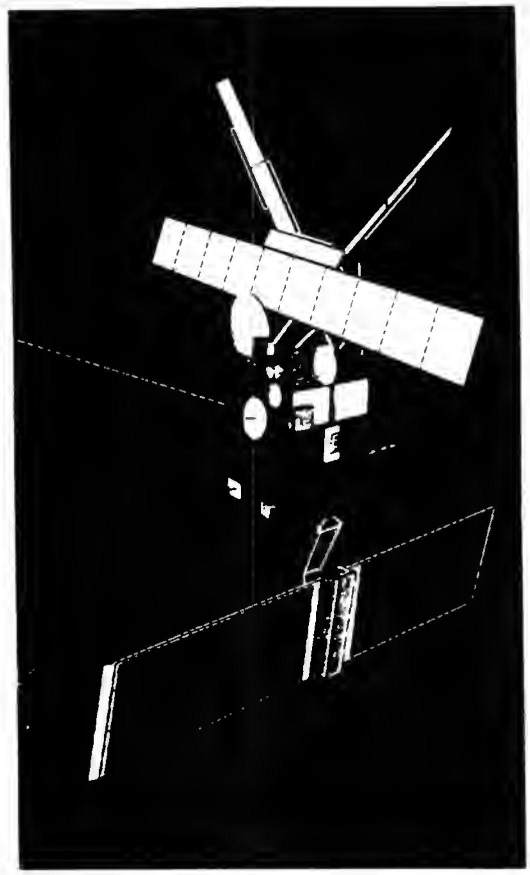


Figure 5. Artist's impression of the GOME instrument aboard ERS-2

The instrument's design

As a general principle, the GOME instrument collects light arriving from the Sun-illuminated Earth's atmosphere and decomposes it into its spectral components. In order to provide both the required spectral coverage from 240 to 790 nm and a good spectral resolution of 0.2–0.4 nm, this decomposition is done in two steps: first by a quartz pre-disperser prism, in which the light is split into four different channels. Each of these channels contains a grating as second dispersing element, and a 1024-pixel silicon array detector (the integration times on the chip can be multiples of 93.75 ms, with 1.5 s for the visible and 30 s for the ultraviolet being the default values)

The entire GOME instrument can be broken down into the following functional blocks:
- the spectrometer
- the four Focal-Plane Assemblies (FPAs)
- the Calibration Unit
- the scan unit with the scanning mechanism and the scan unit electronics (SEU) assembly

Figure 4b. Three-day coverage map for GOME

- the Polarisation Measurement Device (PMD)
- the Digital Data Handling Unit (DDHU)
- the optical bench structure
- the thermal control hardware.

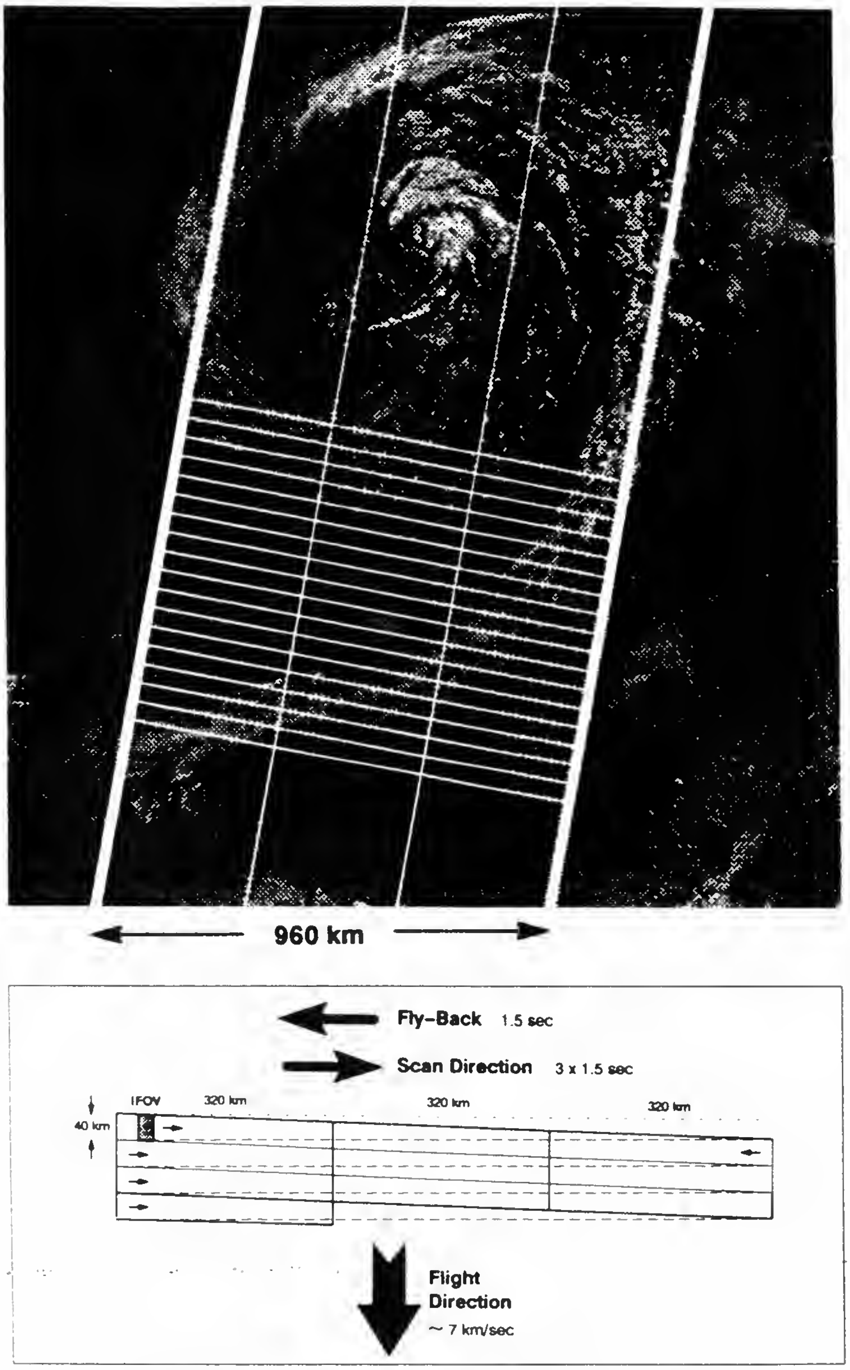


Figure 6. GOME scan pattern (graphic courtesy of DLR, Oberpfaffenhofen)

Table 1. Key optics performance parameters

Band	Wavelength range (nm)	Grating (l/mm)	Pixel resolution (nm)	Spectral resolution (nm)
1A	240–268	3600	0 11	0 22
1B	268–295			
2A	290–312	2400	0 12	0 24
2B	312–405			
3	400–605	1200	0 2	0 4
4	590–790	1200	0 2	0 4

Spectrometer optics

In the spectrometer optics, shown schematically in Figure 7, the light reflected off the scanning mirror is focussed by an anamorphic telescope such that the shape of the focus matches the entrance slit of the spectrometer (dimensions 10 mm x 100 µm. After the slit, the light is collimated by an off-axis parabolic mirror. It then strikes the quartz pre-disperser prism, causing a moderately wavelength dispersed beam. Another prism acts as channel separator: the upper edge of this prism reaches into the wavelength-dispersed beam, letting the longer wavelengths pass, reflecting the wavelength range 290–405 nm into Channel 2 by means of a dielectric reflecting coating, and guiding the wavelength range 240–295 nm internal to the prism into Channel 1. The unaffected wavelength range of 405–790 nm is then split up by a dichroic beam splitter into Channels 3 (400–605 nm) and 4 (590–790 nm).

Each individual channel consists of an off-axis parabola, a grating, and an objective with f-numbers of 2 (Channels 1 and 2) and 3 (Channels 3 and 4), finally focussing the light onto the detectors contained in their respective Focal-Plane Assemblies.

The most critical optical elements in the optical chain are the diffraction gratings, which have to provide both a high efficiency in the first diffraction order and a very low level of stray light and ghosting. Because of the criticality of the gratings for the final performance of the instrument, two parallel development programmes are under way, at the firms of Jobin-Yvon in France and Carl Zeiss in Germany. Some of the key performance requirements for the optics are summarised in Table 1.

Focal-Plane Assemblies

The FPAs are made from titanium and have a sealed quartz window at the side where they are flanged to the respective objective tubes. The rear side of the FPA, the so-called 'pin-plate', is a titanium plate provided with electrically isolated, vacuum-tight feed-throughs for the electrical connections to the detector. This is a Reticon RL 1024 SR random-access diode array detector with 1024 pixels, each pixel measuring 25 µm in the dispersion direction and 2.5 mm in the along-slit direction. Each diode is randomly accessible by an address bus and can be read out individually.

In the GOME instrument, the detectors of Channels 1 and 2 are split into several

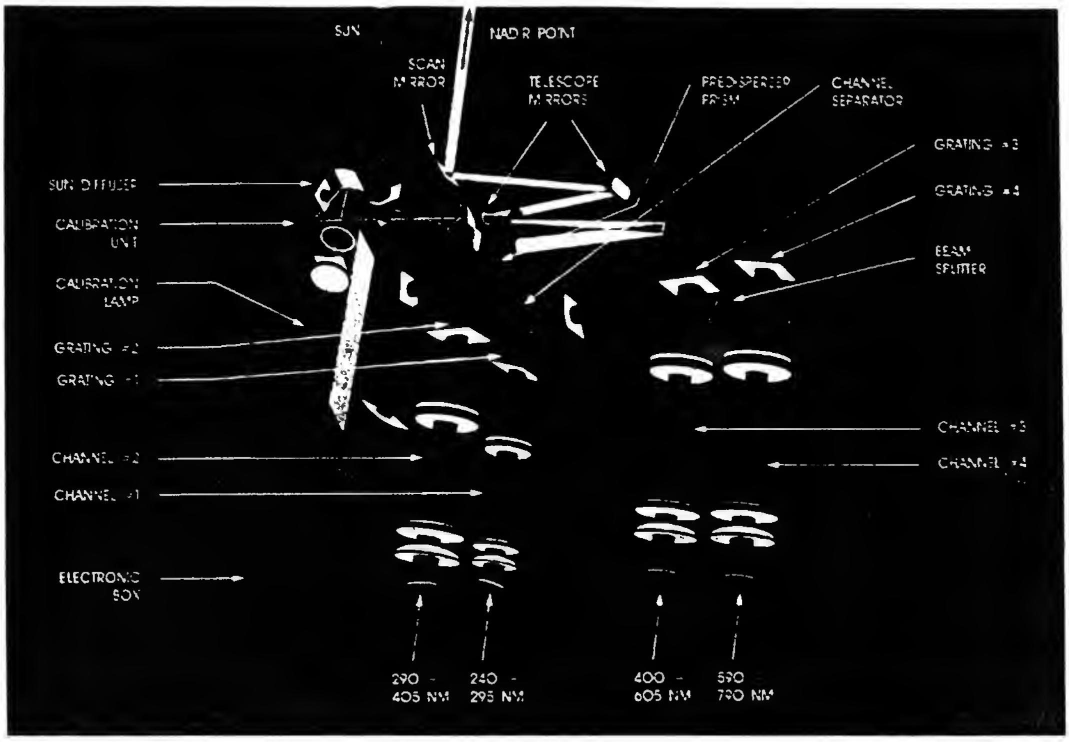


Figure 7. Spectrometer optics

bands, the integration times of which may be varied individually. The Reticon detector chip is shown in Figure 8. The detectors are glued onto two-stage Peltier coolers, which reduce their temperature to −40°C to keep the dark current of the photodiodes sufficiently low The hot side of the Peltier coolers is glued (in the engineering model), respectively brazed (in the flight model), to a copper bar, extending through the pin-plate. Outside the FPA, this copper bar is connected via flexible connections and heat pipes to the main radiator. The tips carrying the Peltier coolers and detectors are tilted between 1.6° and 9.5° to compensate for chromatic aberration.

At the back side of the FPA, the Front-End Electronics (FEE) are mounted on a printed-circuit board. They are based on a charge amplifier implemented with a low-noise amplifier and a dual-FET input stage. The output of the FEE is fed to the Digital Data Handling Unit (DDHU), where it is further processed and digitised.

During ground operations, the FPAs can be either evacuated, or filled with dry nitrogen to avoid moisture freezing out on the cooled detectors. In addition, the polarity of the Peltier elements can be inverted to heat the detectors to +80° to drive off possible contaminants and to anneal radiation effects Once in orbit, the FPAs are exposed to the vacuum of space by a burst membrane, which is designed to open during the launch phase.

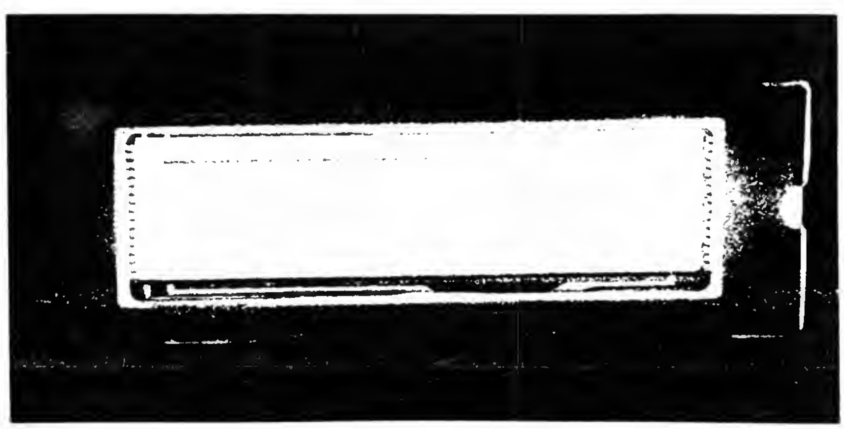
Calibration unit

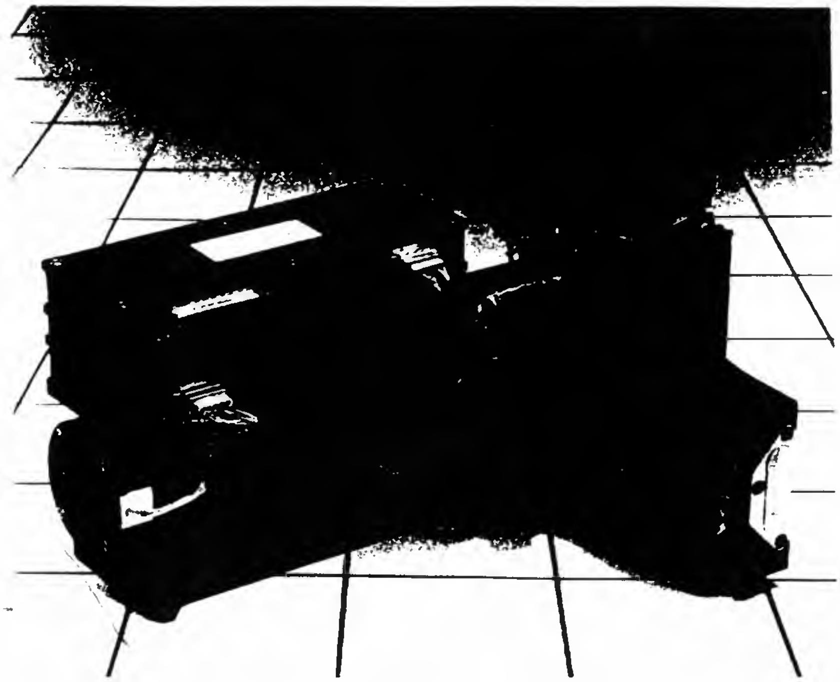
In order to support the DOAS technique, one would like to have a wavelength stability of 1/100 th of a pixel. This is not achievable with a passive thermal design in such a power-limited situation Instead, wavelength position on the detector pixels versus orbital temperature will be mapped by means of a hollow-cathode lamp (Pt-Cr-Ne) which provides a sufficient number of sharp lines in all wavelength regions.

For the radiometric calibration, the Sun will be used as the source. Because of the orbital and scanner geometry, which prevents direct viewing of the Sun via the scanning mirror, and because its high intensity would lead (even with the shortest possible integ-ration time) to detector saturation, the Sun is viewed via a diffuser plate accommodated in the calibration unit (Fig. 9).

Previous NASA experience has shown that the diffuser is subject to degradation during its periods of exposure. Precautions are therefore taken by having:

Figure 8. Reticon RL1024SR detector chip





igure 9. Calibration unit

- a mesh in front of the diffuser, attenuating the incoming light level and largely protecting the diffuser
- a shutter mechanism that opens only during Sun calibration and protects the diffuser during the remaining mission phases
- the possibility to view the calibration lamp via the diffuser, thereby having a means to monitor possible degradation, at least at those wavelengths provided by the lamp.

Scanning unit

The scanning unit consists of two separate assemblies, the Scan Mechanism (SM) and the Scan Unit Electronics Assembly (SUEA). The scan mechanism is located on the optical bench, with its rotation axis aligned with the satellite's flight direction. The axis carries a glued-on aluminium-coated mirror, which can be heated from the rear to drive off possible contaminants, if necessary.

A brushless DC motor actuates the scanner, the position of which is sensed by a resolver. The rotating part of the resolver, the mirror heater and the temperature sensor are connected to the static part via a flexible printed-circuit connection. The angular range of the scanner is limited to −63.8 to +192.2° with respect to nadir (0°) by software and end stops

The rotation axis is supported by two spring-preloaded angular contact bearings, the balls of which are ion-plated with lead and the races are made of lead bronze. All structural parts (housing, pivot, etc.) are made from titanium

Polarisation measurement device

The incoming light from the Earth's atmosphere can be partially polarised. Because the instrument's responses to the two orthogonal linear polarisation directions are not equal, there is a need to monitor the polarisation of the incoming light.

In the pre-disperser prism, light is internally reflected at the Brewster angle. About 5 % of this light, polarised normal to the plane of incidence, leaks away at this surface. This light is collected by an off-axis parabola, reflected by a mirror out of the plane of the optical bench, and then sensed by a custom-made photodiode array.

Because the device is not temperature-controlled, it is subject to drifts. To keep the impact of changing temperatures to a minimum, a second array of photodiodes with the same geometry, but not exposed to light, will be used to compensate for the dark current and its variability with temperature.

The measured signals are acquired by the DDHU, converted to digital signals, and included into the telemetry data (3 x 16 bit, 10.67 Hz).

Digital Data-Handling Electronics (DDHU)

The prime interface to the satellite's electrical subsystems is via the Digital Electronics Unit (DEU) of the Along-Track Scanning Radiometer (ATSR). Because the DEU now not only controls the ATSR's Infrared Radiometer (IRR) and Microwave Radiometer (MWR), but also GOME, a redundant DEU has been added, together with a DEU Switching Unit (DSU)

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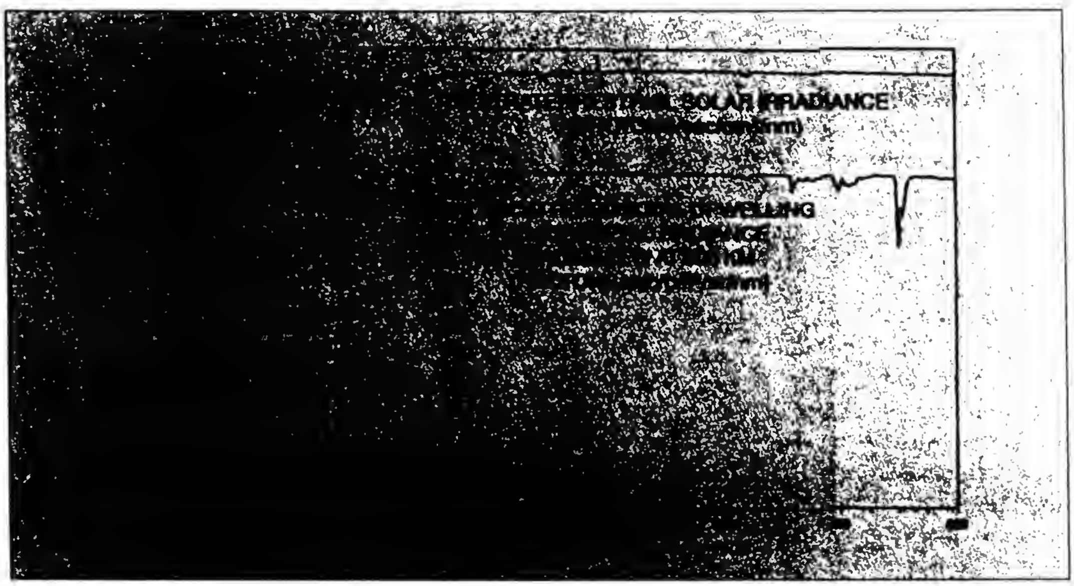

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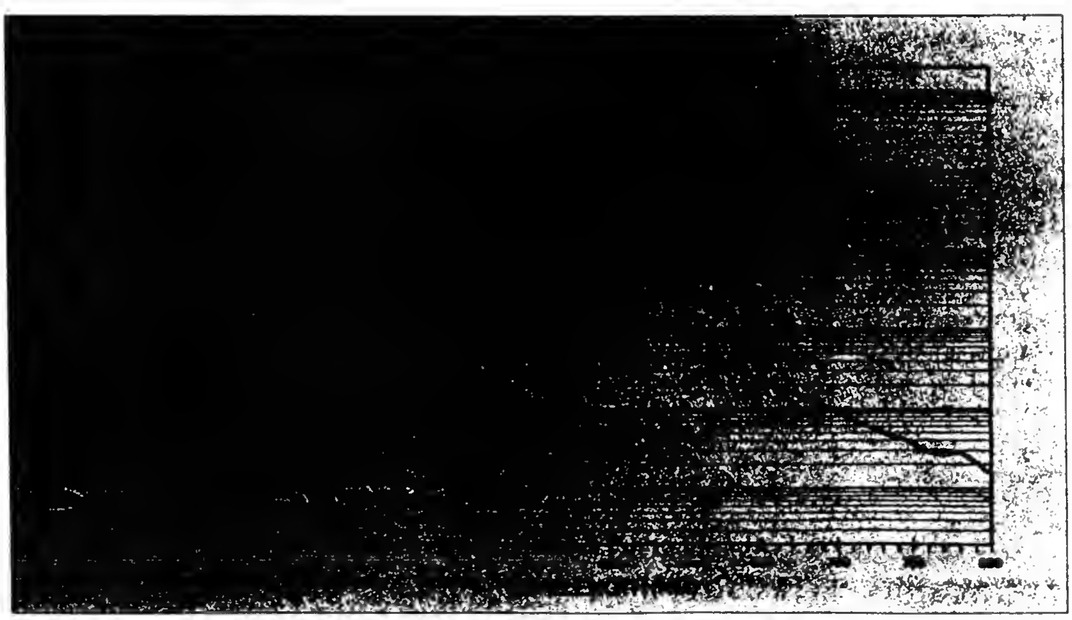

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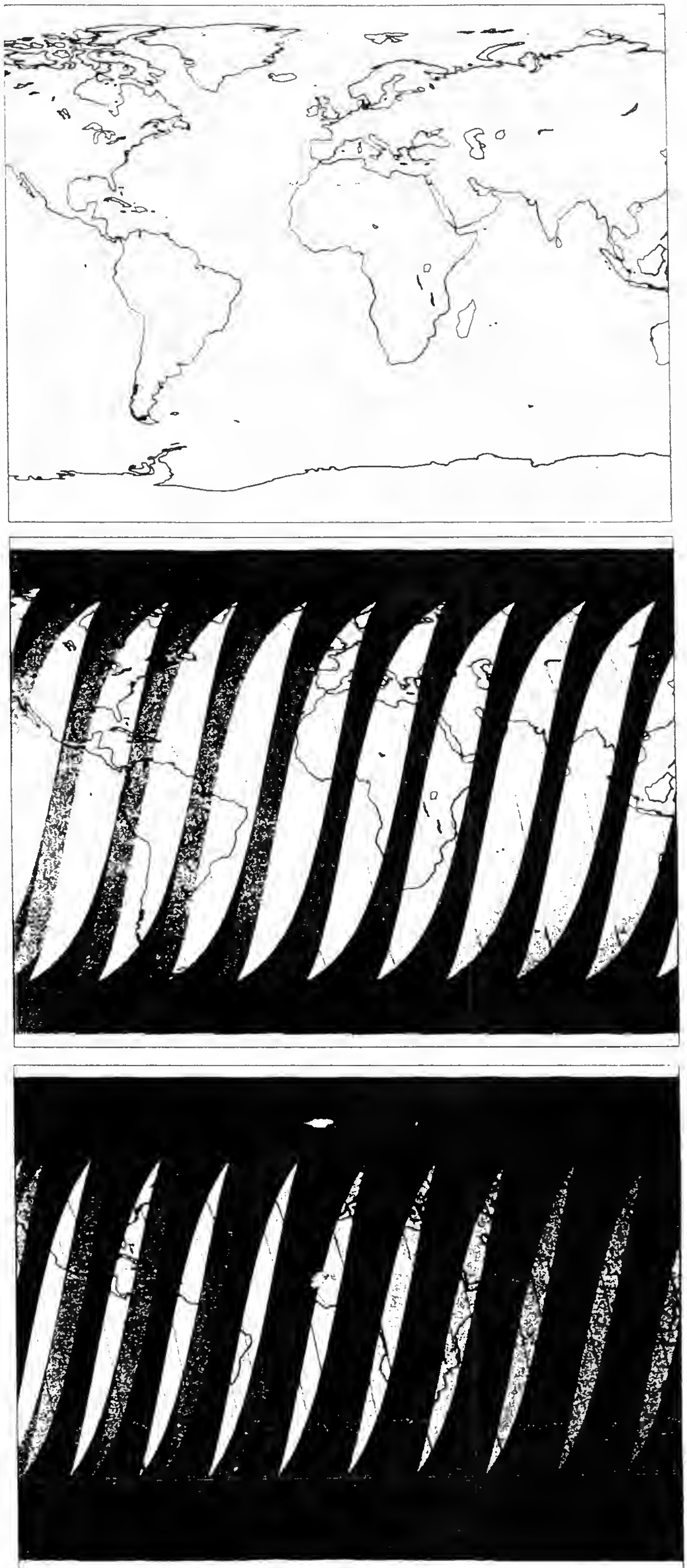
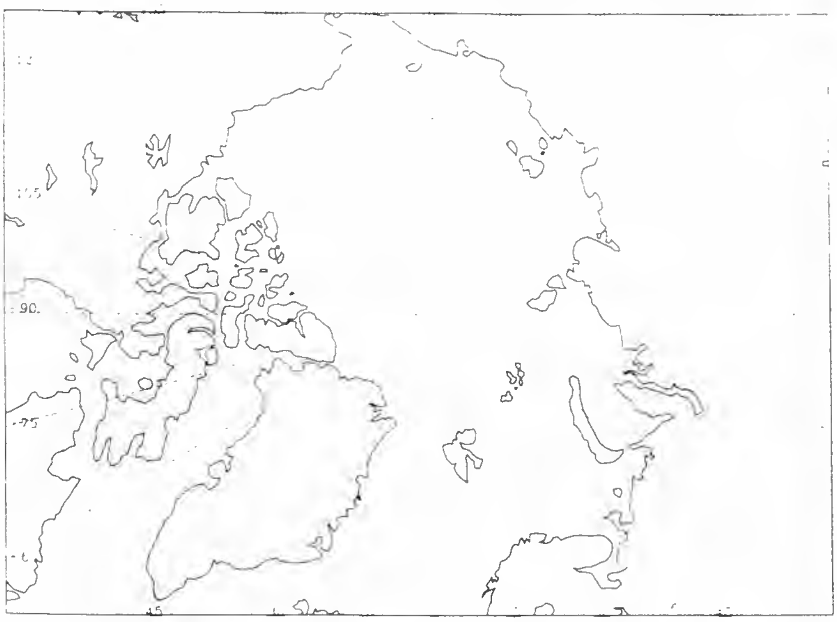
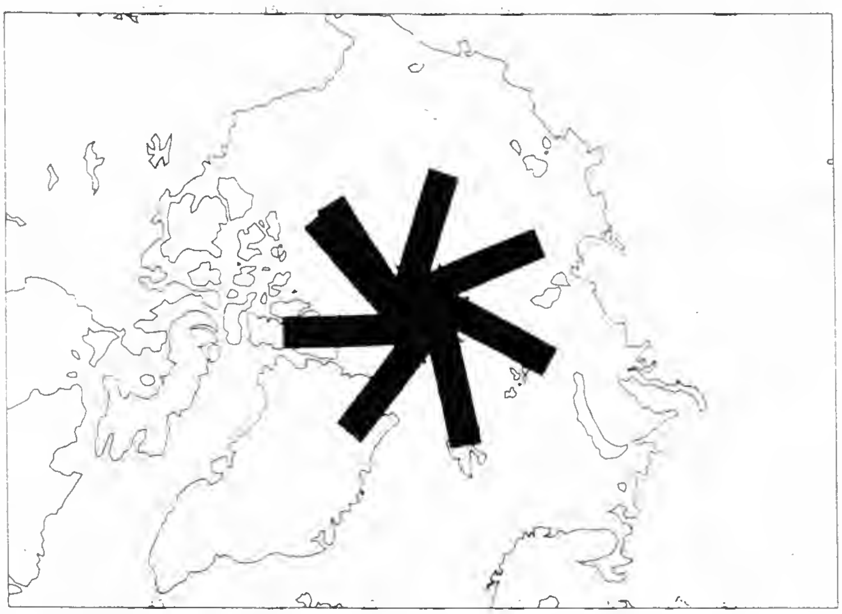
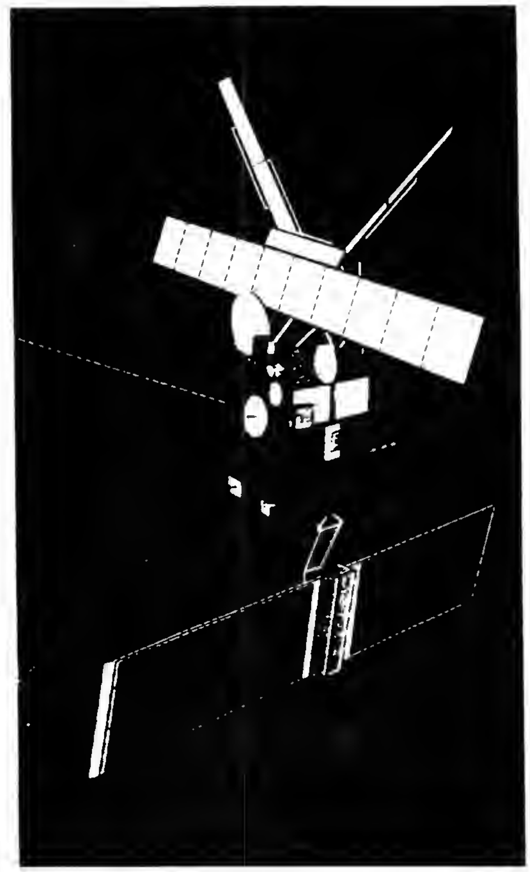


Figure 4a. Three-day coverage map for GOME







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The entire GOME instrument can be broken down into the following functional blocks:
- the spectrometer
- the four Focal-Plane Assemblies (FPAs)
- the Calibration Unit
- the scan unit with the scanning mechanism and the scan unit electronics (SEU) assembly

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- the Digital Data Handling Unit (DDHU)
- the optical bench structure
- the thermal control hardware.

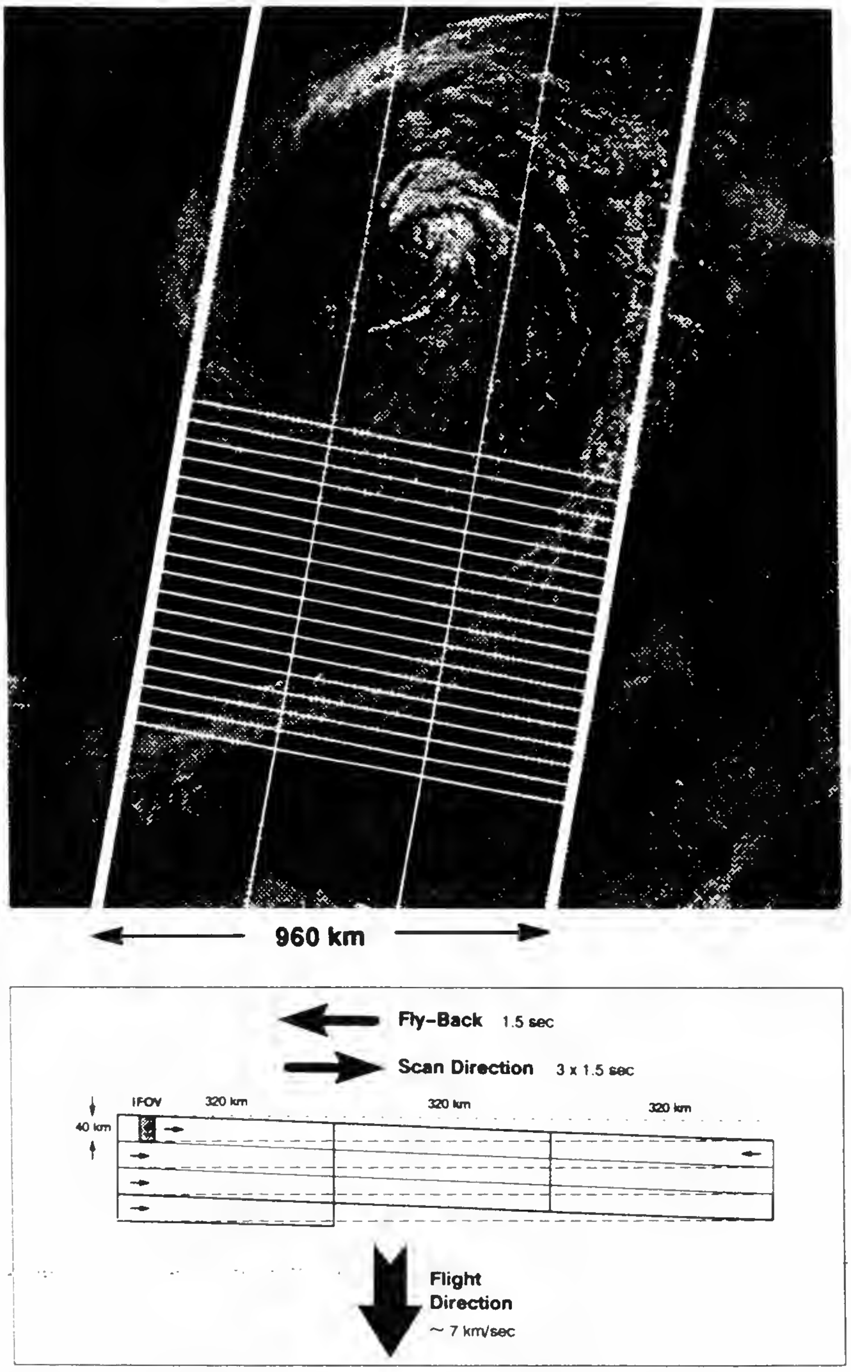

Figure 6. GOME scan pattern (graphic courtesy of DLR, Oberpfaffenhofen)

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Band	Wavelength range (nm)	Grating (l/mm)	Pixel resolution (nm)	Spectral resolution (nm)
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In the spectrometer optics, shown schematically in Figure 7, the light reflected off the scanning mirror is focussed by an anamorphic telescope such that the shape of the focus matches the entrance slit of the spectrometer (dimensions 10 mm x 100 µm. After the slit, the light is collimated by an off-axis parabolic mirror. It then strikes the quartz pre-disperser prism, causing a moderately wavelength dispersed beam. Another prism acts as channel separator: the upper edge of this prism reaches into the wavelength-dispersed beam, letting the longer wavelengths pass, reflecting the wavelength range 290–405 nm into Channel 2 by means of a dielectric reflecting coating, and guiding the wavelength range 240–295 nm internal to the prism into Channel 1. The unaffected wavelength range of 405–790 nm is then split up by a dichroic beam splitter into Channels 3 (400–605 nm) and 4 (590–790 nm).

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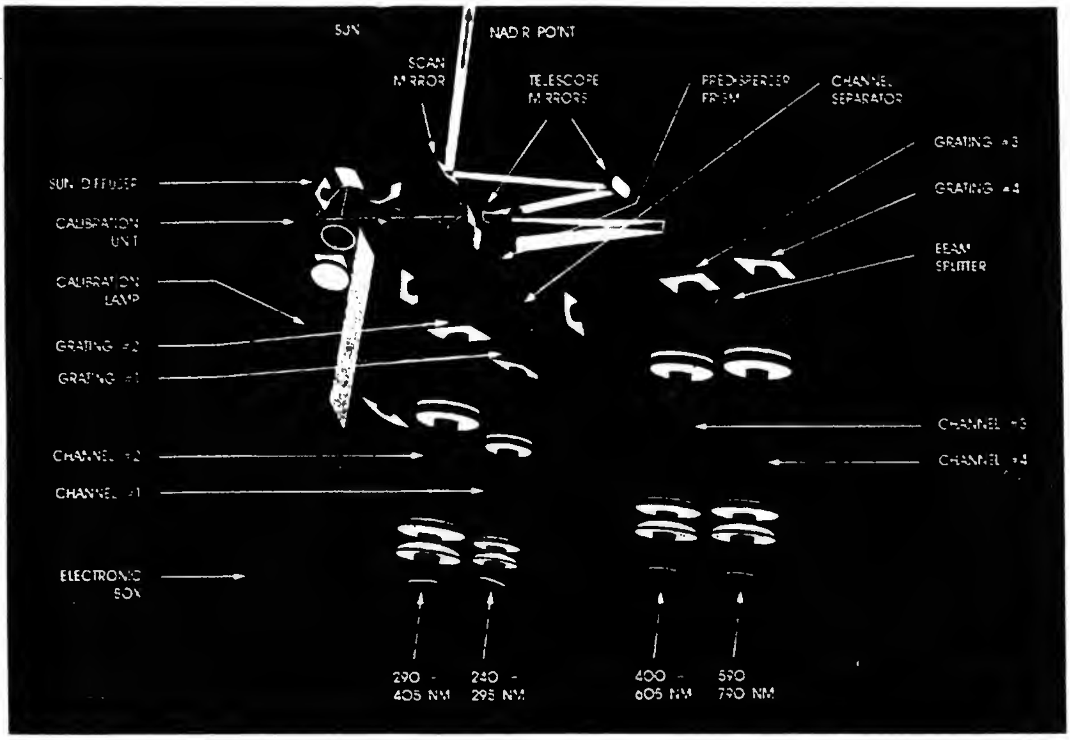

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bands, the integration times of which may be varied individually. The Reticon detector chip is shown in Figure 8. The detectors are glued onto two-stage Peltier coolers, which reduce their temperature to −40°C to keep the dark current of the photodiodes sufficiently low. The hot side of the Peltier coolers is glued (in the engineering model), respectively brazed (in the flight model), to a copper bar, extending through the pin-plate. Outside the FPA, this copper bar is connected via flexible connections and heat pipes to the main radiator. The tips carrying the Peltier coolers and detectors are tilted between 1.6° and 9.5° to compensate for chromatic aberration.

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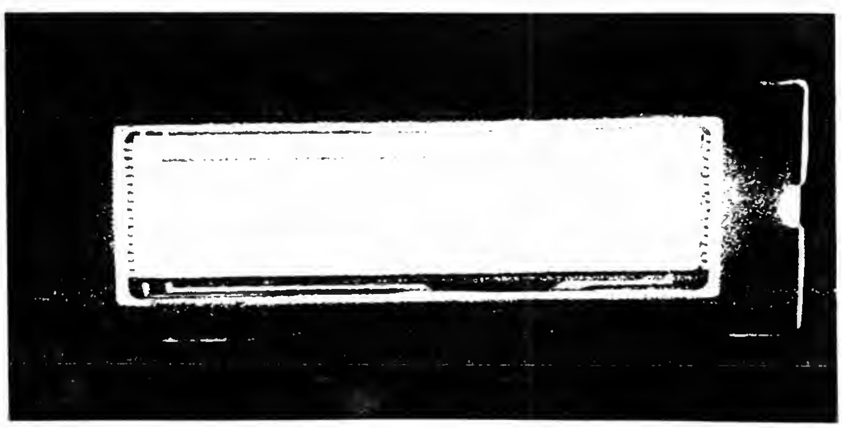
Calibration unit

In order to support the DOAS technique, one would like to have a wavelength stability of 1/100 th of a pixel. This is not achievable with a passive thermal design in such a power-limited situation. Instead, wavelength position on the detector pixels versus orbital temperature will be mapped by means of a hollow-cathode lamp (Pt-Cr-Ne) which provides a sufficient number of sharp lines in all wavelength regions.

For the radiometric calibration, the Sun will be used as the source. Because of the orbital and scanner geometry, which prevents direct viewing of the Sun via the scanning mirror, and because its high intensity would lead (even with the shortest possible integration time) to detector saturation, the Sun is viewed via a diffuser plate accommodated in the calibration unit (Fig. 9).

Previous NASA experience has shown that the diffuser is subject to degradation during its periods of exposure. Precautions are therefore taken by having:

Figure 8. Reticon RL1024SR detector chip



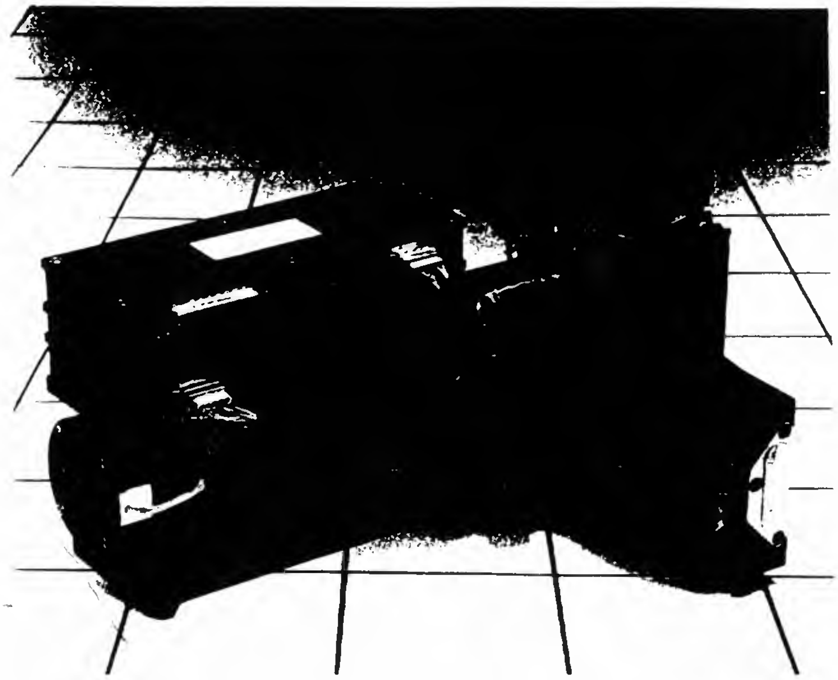


Figure 9. Calibration unit

- a mesh in front of the diffuser, attenuating the incoming light level and largely protecting the diffuser
- a shutter mechanism that opens only during Sun calibration and protects the diffuser during the remaining mission phases
- the possibility to view the calibration lamp via the diffuser, thereby having a means to monitor possible degradation, at least at those wavelengths provided by the lamp.

Scanning unit

The scanning unit consists of two separate assemblies, the Scan Mechanism (SM) and the Scan Unit Electronics Assembly (SUEA). The scan mechanism is located on the optical bench, with its rotation axis aligned with the satellite's flight direction. The axis carries a glued-on aluminium-coated mirror, which can be heated from the rear to drive off possible contaminants, if necessary.

A brushless DC motor actuates the scanner, the position of which is sensed by a resolver. The rotating part of the resolver, the mirror heater and the temperature sensor are connected to the static part via a flexible printed-circuit connection. The angular range of the scanner is limited to −63.8 to +192.2° with respect to nadir (0°) by software and end stops.

The rotation axis is supported by two spring-preloaded angular contact bearings, the balls of which are ion-plated with lead and the races are made of lead bronze. All structural parts (housing, pivot, etc.) are made from titanium.

Polarisation measurement device

The incoming light from the Earth's atmosphere can be partially polarised. Because the instrument's responses to the two orthogonal linear polarisation directions are not equal, there is a need to monitor the polarisation of the incoming light.

In the pre-disperser prism, light is internally reflected at the Brewster angle. About 5 % of this light, polarised normal to the plane of incidence, leaks away at this surface. This light is collected by an off-axis parabola, reflected by a mirror out of the plane of the optical bench, and then sensed by a custom-made photodiode array.

Because the device is not temperature-controlled, it is subject to drifts. To keep the impact of changing temperatures to a minimum, a second array of photodiodes with the same geometry, but not exposed to light, will be used to compensate for the dark current and its variability with temperature.

The measured signals are acquired by the DDHU, converted to digital signals, and included into the telemetry data (3 x 16 bit, 10.67 Hz).

Digital Data-Handling Electronics (DDHU)

The prime interface to the satellite's electrical subsystems is via the Digital Electronics Unit (DEU) of the Along-Track Scanning Radiometer (ATSR). Because the DEU now not only controls the ATSR's Infrared Radiometer (IRR) and Microwave Radiometer (MWR), but also GOME, a redundant DEU has been added, together with a DEU Switching Unit (DSU).

The DEU assumes all the normal functions of an Instrument Control Unit (ICU). Commands dedicated to GOME are expanded into a serial digital bit stream, initiating the appropriate actions within the DDHU. In the opposite direction, both housekeeping and scientific data are written by the DDHU into data buffers, from which they are requested by the DEU to be put into predefined fields of the ATSR S-band and X-band data streams.

Thermal-control hardware

The most critical aspect of the thermal control is the detector temperature, which is provided by the Peltier elements in each of the Focal-Plane Assemblies. The hot sides of the Peltiers are all connected, via copper bars and flexible connections, to a parallel pair of bent heat pipes, which end in the primary radiator exposed to deep space.

The DDHU and the scanning mirror electronics assembly have their own radiative surfaces for thermal control. The remainder of the instrument is wrapped in multi-layer insulation blankets. For cold non-operational phases, thermostat-controlled heater mats and resistors are directly powered from the payload's Power Distribution Unit.

Structure

All elements of the optics, mechanisms, electronics and thermal hardware are mounted on the optical bench, which is a nearly rectangular aluminium plate with stiffening ribs beneath. This optical bench is carried on four feet, one of which is round in cross-section and rather stiff. The other three are blade-shaped feet, with their flexing direction lying in the direction of the fixed foot. This prevents mechanical distortion of the optical alignment due to thermal expansion of the bench.

Beneath the optical bench, in the space between the ribs, the harness and the pipework for FPA evacuation are routed. An EMC shield protects the instrument from electromagnetic interference from the satellite's radars and communications system.

Operations

The GOME instrument has numerous measurement, calibration, and support modes. In particular, due to the varying light levels that will be experienced during each orbit, integration time settings will have to be adjusted frequently. In addition, once per day a Sun calibration has to be performed.

In order to limit the command traffic on the uplink, the DEU stores three different timelines, each of which can be activated automatically up to 16 times in sequence. One of these timelines is for normal operations, one for an orbit in which a Sun calibration is being performed, and one with a sidewards swath to cover the polar area (with the normal nadir-centred swath there would be a gap in coverage of about 4° around both poles).

About once per month, a wavelength mapping as function of the thermal variations will be performed with the wavelength calibration lamp. On these occasions a diffuser characterisation can also be carried out.

Lunar observations, which are restricted by the Sun–Moon–satellite scanner field-of-view geometry, will be performed whenever possible.

Data processing

GOME data will arrive together with the other 'low-bit-rate' data at the various ground stations to which the ERS tape recorders are downlinked. Extracted GOME data, together with orbit and attitude information, will then be shipped on Exabyte cassettes to the German Processing and Archiving Facility (D-PAF) in Oberpfaffenhofen. In a first processing step, the raw data will be corrected for instrument-induced errors and drifts, and provided with information on geo-location, Sun aspect angle, etc.

From these radiometrically and wavelength corrected geo-located spectra, the ozone total column amount, ozone vertical concentration profile, and data on aerosol loading and cloud cover can be retrieved. This will be done at distributed centres, according to the particular scientific expertise available. Time and budgets permitting, other atmospheric-constituent retrieval can be added to the range of data products generated. Finally, time and spatial averaging for long-term global-trend analyses is likely to be conducted (not yet specifically defined).

In addition to this off-line processing chain, some limited processing capabilities will also be installed at ESTEC, in order to evaluate the instrument performance after launch, optimise parameter settings and operating schemes, and to support possible scientific campaigns.

GOME should produce unique data as there will be no other instrument available on its time scale which duplicates its capabilities. The instrument fills a critical slot as far as future observing strategies are concerned, and GOME could well become the prototype for subsequent ozone-monitoring instruments. Its medium spectral resolution combined with a wide spectral range and absolute calibration is particularly important as it means that, in addition to applying the traditional backscatter approach, one can also use differential optical absorption spectroscopy to retrieve data with GOME.

Acknowledgements

We gratefully acknowledge the unfailing support of the GOME Science Team, headed by Prof. Dr. J. Burrows from the University of Bremen (D). Much of the work reported here has been done by the GOME Industrial Team, comprised of Officine Galileo (I), Laben (I), TPD/TNO (NL), Dornier (D) and the Rutherford Appleton Laboratory (UK), and BAe (UK) for the DEU modifications.

GOME: A New Instrument for ERS-2

A. Hahne, A. Lefebvre, J. Callies & R. Zobl
ERS Project Division, ESA Directorate for Observation of the Earth and Its Environment, ESTEC, Noordwijk, The Netherlands

The Global Ozone Monitoring Experiment, or GOME, is a new instrument that will be added to the original ERS-1 payload complement for the launch of the second European Remote-Sensing Satellite (ERS-2) in 1994. GOME is a nadir-viewing spectrometer which will observe solar radiation transmitted through or scattered from the Earth's atmosphere or from its surface. The recorded spectra will be used to derive a detailed picture of the atmosphere's content of ozone, nitrogen dioxide, water vapour, oxygen/oxygen dimer and bromine oxide and other trace gases. ERS-2's orbit will provide global Earth coverage every three days.

Introduction

In 1989, ESA decided to continue the ERS Programme beyond the expected lifetime of the ERS-1 satellite by approving the building and launch of the ERS-2 satellite. To provide the necessary continuity to the observations started by the instruments of ERS-1, ERS-2 is essentially a carbon-copy of the ERS-1 satellite. It was recognised, however, that there is an urgent need to investigate the composition and dynamic behaviour of the Earth's atmosphere. The ERS-2 Programme approval therefore included an experimental sensor for atmospheric research, the 'Global Ozone Monitoring Experiment' (GOME), which is essentially a scaled-down version of the SCIAMACHY instrument proposed for the European Polar Platform to be launched at the end of the century.

The inclusion of the GOME sensor in ERS-2 Programme was endorsed on the explicit understanding that:
- the sensor would be developed, tested, calibrated and integrated in the same time frame as the satellite and the other instruments would be rebuilt
- the resource demands of the sensor would have to be satisfied from the existing system margins, imposing stringent limitations on mass, power and data rate
- no major upgrades in the ERS Ground Segment would be needed, and the financial burden for the data-processing algorithms and software would be borne by scientific institutions and/or national agencies.

The limitations on resources have already led to drastic changes in the instrument concept, because at the Baseline Design Review held in February 1991 it became obvious that the power/energy demand exceeded the available margin. Instead of GOME having its own interface to the On-Board Computer (OBC) and to the Instrument Data Handling and Transmission (IDHT) system, it was decided to provide these functions via the existing interfaces of the Along-Track Scanning Radiometer (ATSR) instrument.

Scientific objectives

Ozone (O_3) is a tri-atomic form of oxygen, formed by hard ultraviolet radiation in the atmospheric layer between about 15 and 45 km altitude, the so-called 'stratosphere'. It absorbs radiation in the spectral region between 240 and 310 nm, preventing these harmful rays from reaching the ground in large quantities. This naturally protective atmospheric layer is now being threatened by human activities, in particular by the steady release of chlorfluorocarbons (CFCs) into the atmosphere. The accumulated anthropogenic effects on stratospheric ozone are believed to be causing a steady depletion of the ozone layer by approximately 0.3 % per year.

The chemistry of the stratosphere is very complex. The hard ultraviolet radiation causes the breakup of many of the available species into reactive fragments, which lead to a multitude of possible reactions. Normally, the rates of these reactions depend not only on the nature of the species, but also on local pressure, temperature, radiative fluxes in the different wavelength regions, vertical and horizontal transport processes, etc. Thus, in order to understand the ozone chemistry fully, it is not sufficient just to measure the ozone; one must also monitor the abundances of many other species, including very

reactive intermediate species occurring in only very low concentrations

Reflecting this need, GOME is intended to measure other species as well as to observe aerosols and polar stratospheric clouds which play significant roles in the heterogeneous processes associated with ozone chemistry. It is hoped that some of these species may be observed in the troposphere, another part of the atmosphere believed to be affected by man's activities. However, the presence of clouds may make this difficult.

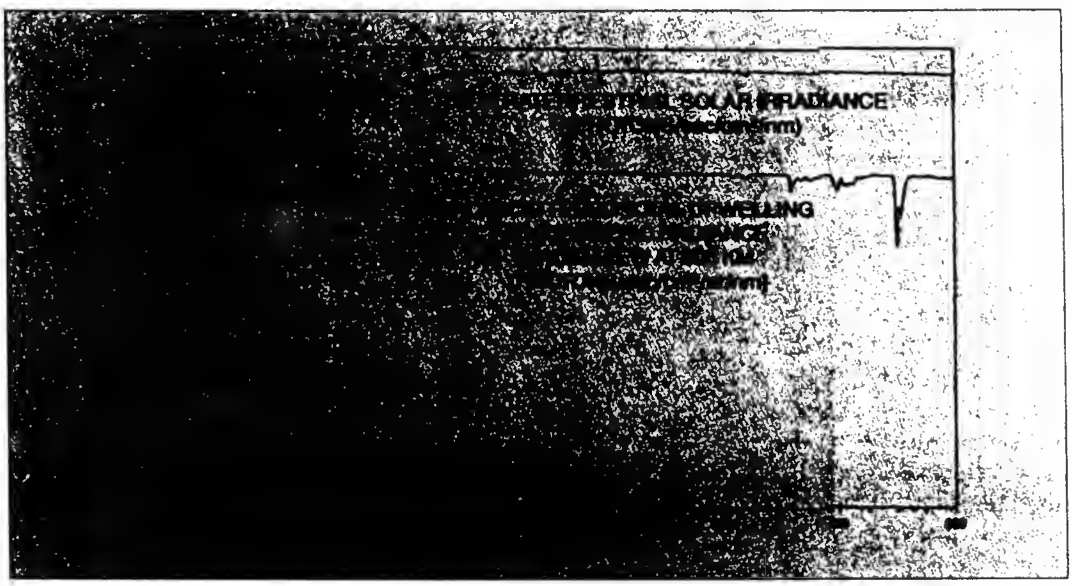
For this GOME will exploit spectroscopy, which is a viable technique for observing trace species in the atmosphere. Sunlight, reflected by the ground surface and scattered within the different atmospheric layers, carries the absorption signatures of the absorbing species (Figs. 1 & 2). The GOME instrument is designed to collect this light over the entire wavelength region from 240 to 790 nm, in which not only ozone, but also a number of other atmospheric species absorb. In addition to the classical backscatter technique, the GOME instrument exploits the novel technique of 'Differential Absorption Spectroscopy' (DOAS)*.

Satellite mission and instrument accommodation

Like its predecessor ERS-1, ERS-2 will fly in a Sun-synchronous polar orbit with an inclination of 98°, with a mean altitude of 780 km and a local time of 10.30 h for the equator crossing on the descending node. This results in an orbital period of approximately 100 min and a ground speed for the subsatellite point of 7 km/s.

The GOME instrument's instantaneous field of view has been chosen to be 40 km x 2 km, or 2.8° x 0.14°. Via the

* Developed by U. Platt (Heidelberg, FRG).



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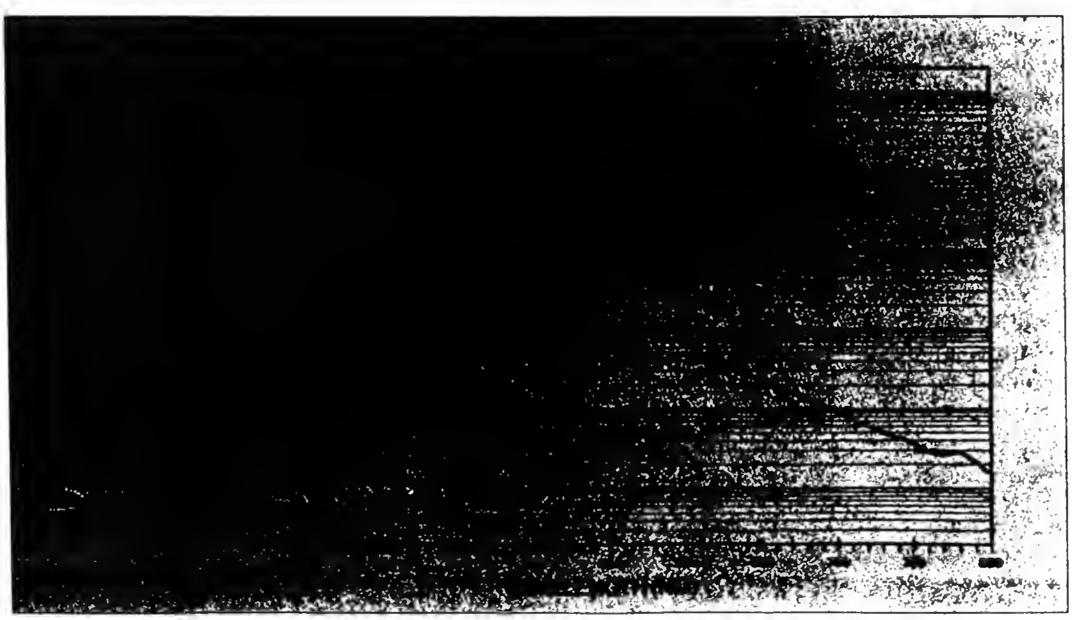

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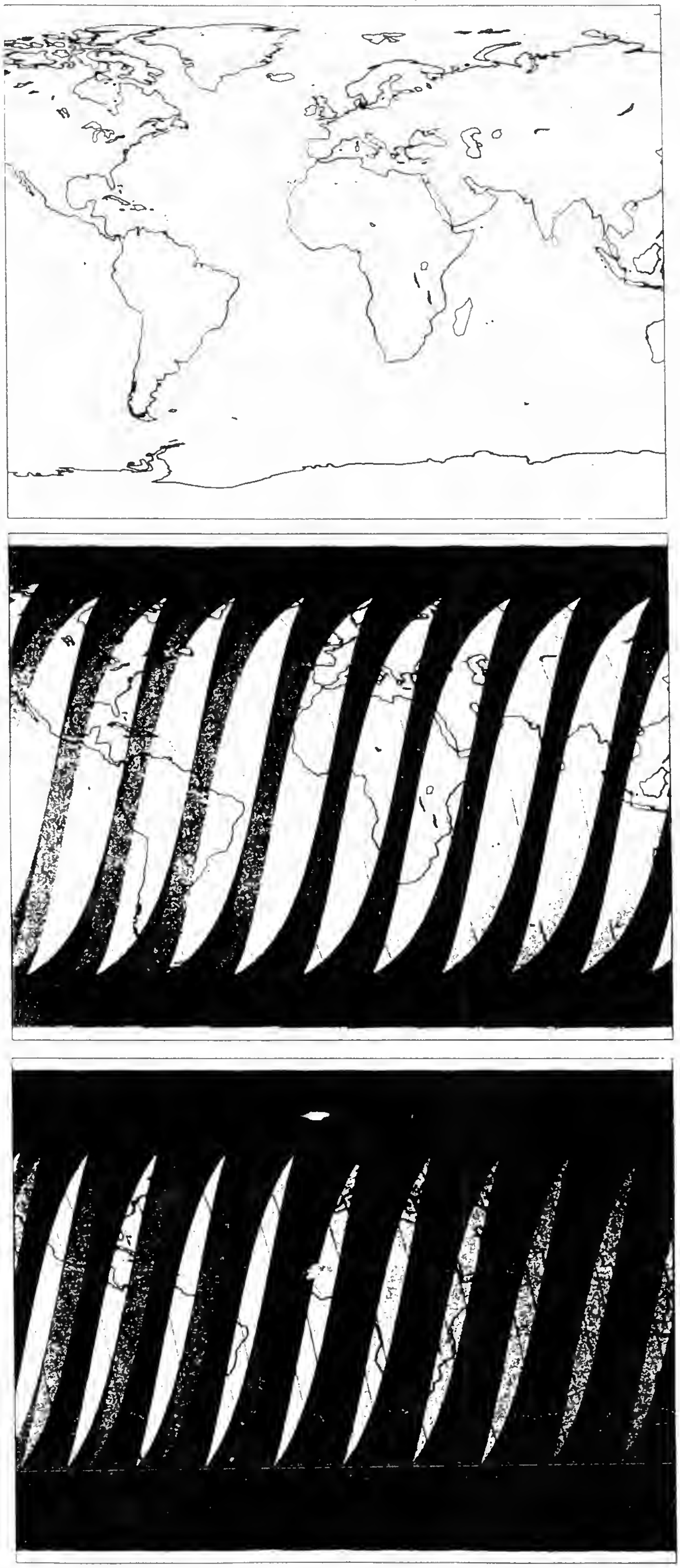

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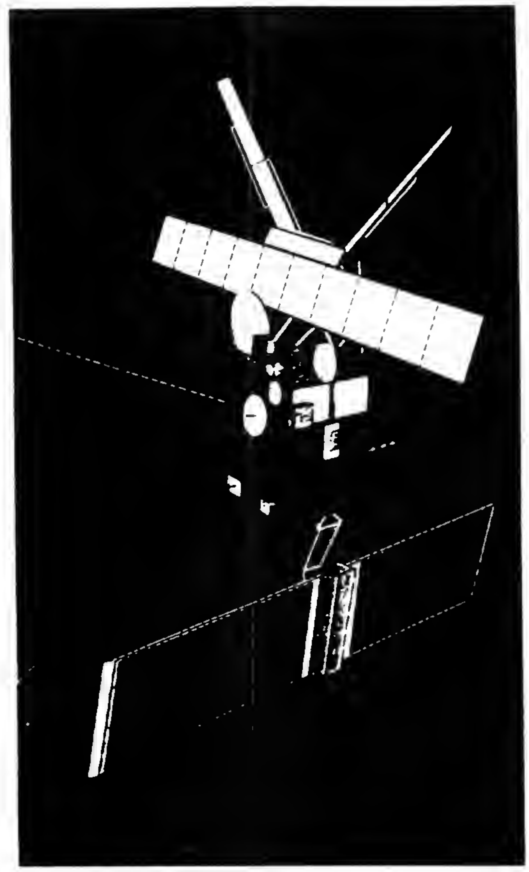

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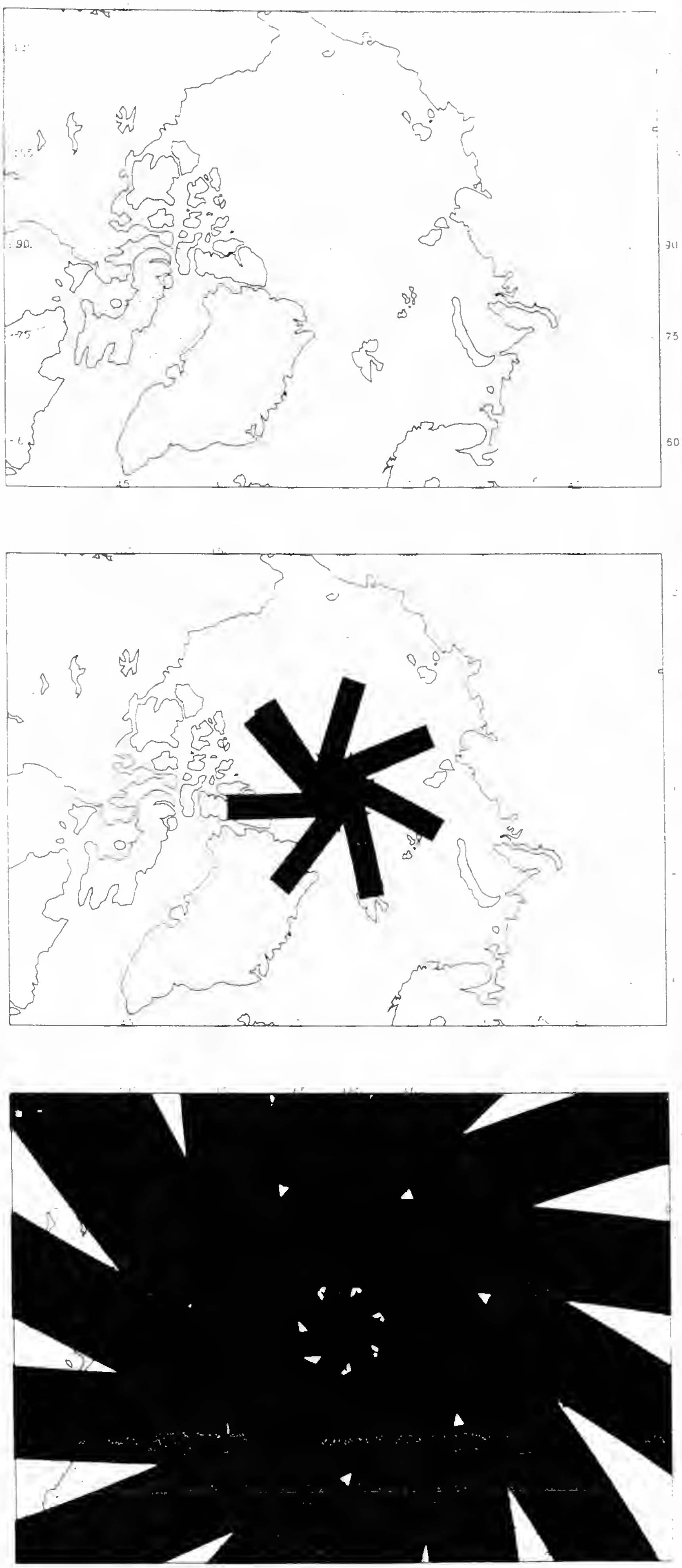

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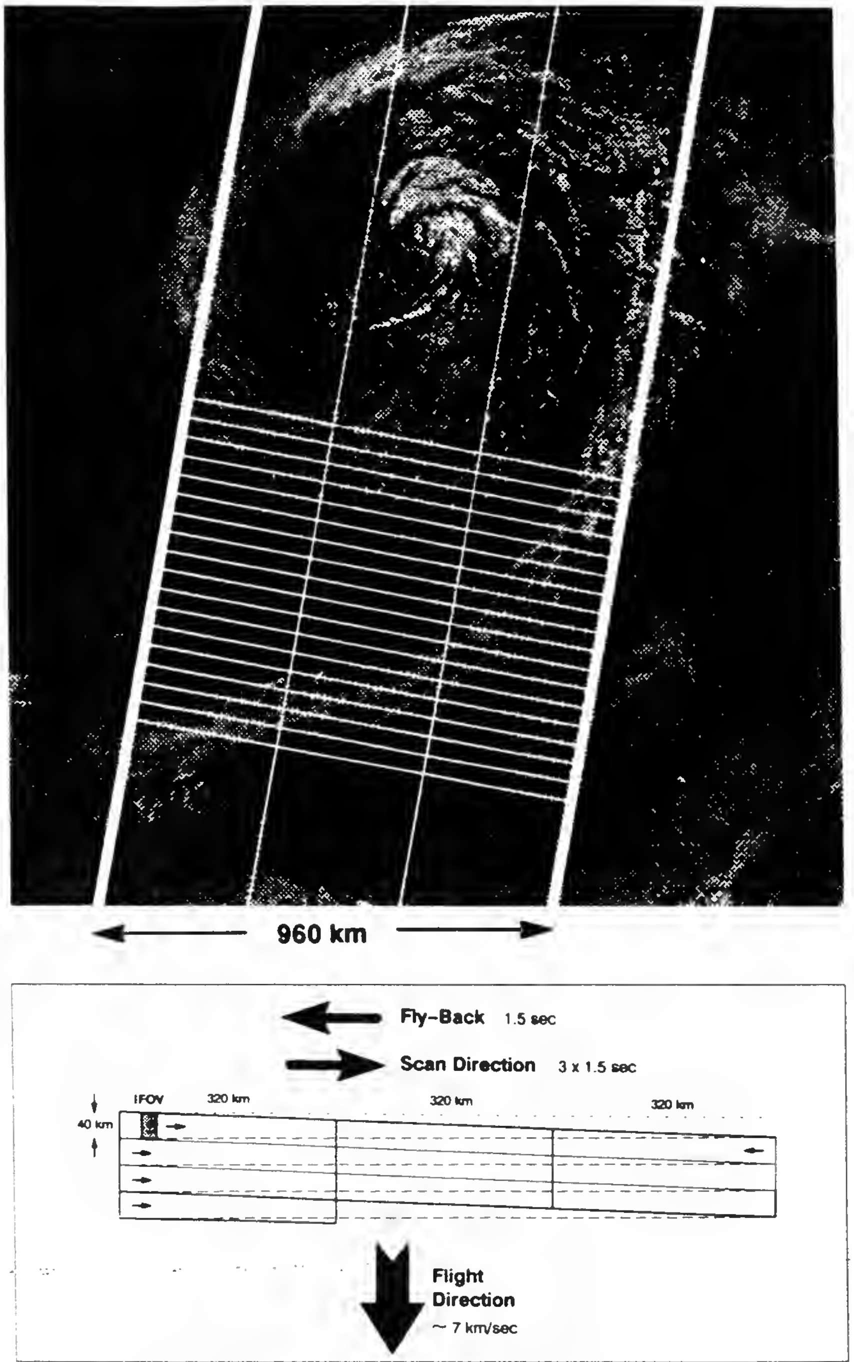

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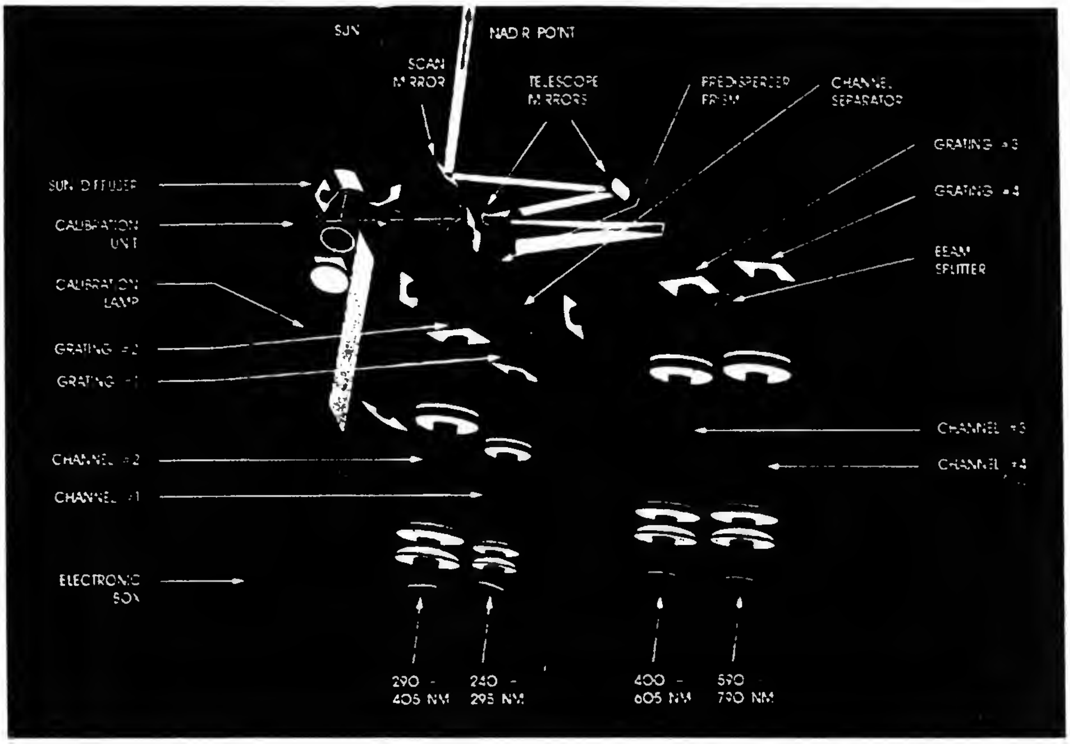

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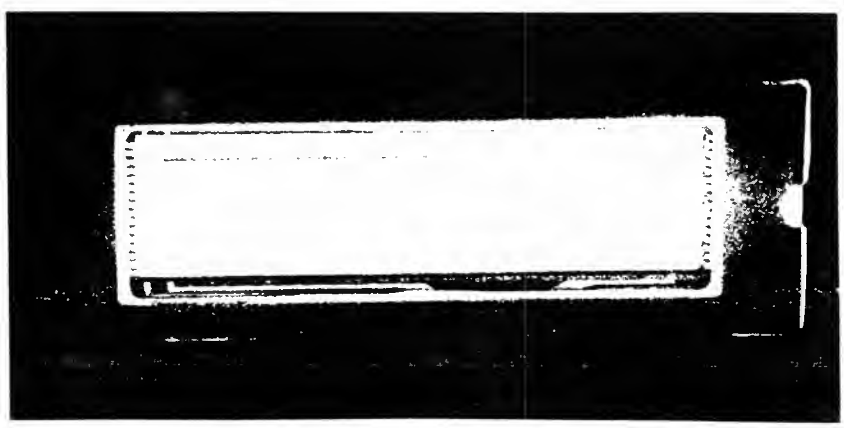
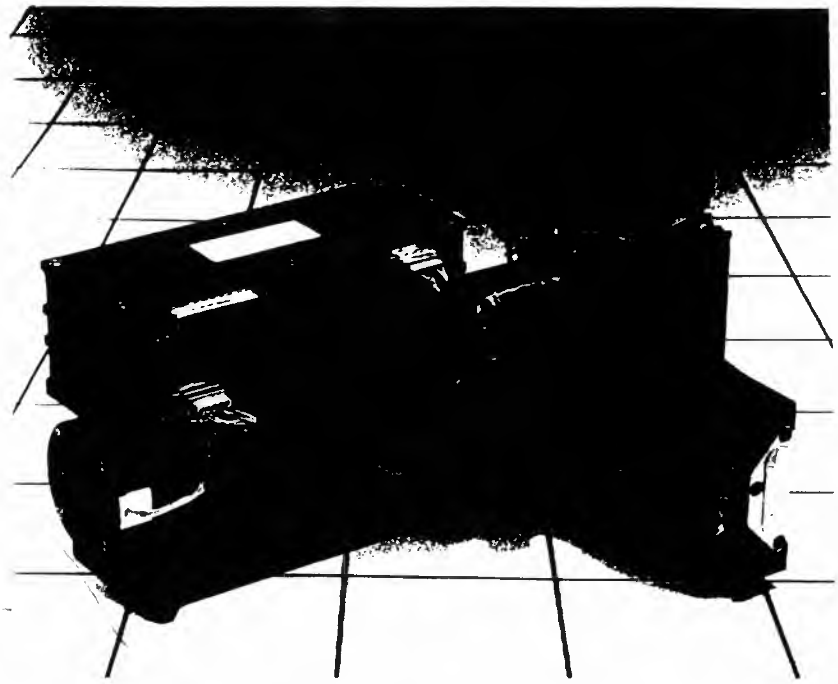
Figure 8. Reticon RL1024SR detector chip





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GOME: A New Instrument for ERS-2

A. Hahne, A. Lefebvre, J. Callies & R. Zobl
ERS Project Division, ESA Directorate for Observation of the Earth and Its Environment, ESTEC, Noordwijk, The Netherlands

The Global Ozone Monitoring Experiment, or GOME, is a new instrument that will be added to the original ERS-1 payload complement for the launch of the second European Remote-Sensing Satellite (ERS-2) in 1994. GOME is a nadir-viewing spectrometer which will observe solar radiation transmitted through or scattered from the Earth's atmosphere or from its surface. The recorded spectra will be used to derive a detailed picture of the atmosphere's content of ozone, nitrogen dioxide, water vapour, oxygen/oxygen dimer and bromine oxide and other trace gases. ERS-2's orbit will provide global Earth coverage every three days.

Introduction

In 1989, ESA decided to continue the ERS Programme beyond the expected lifetime of the ERS-1 satellite by approving the building and launch of the ERS-2 satellite. To provide the necessary continuity to the observations started by the instruments of ERS-1, ERS-2 is essentially a carbon-copy of the ERS-1 satellite. It was recognised, however, that there is an urgent need to investigate the composition and dynamic behaviour of the Earth's atmosphere. The ERS-2 Programme approval therefore included an experimental sensor for atmospheric research, the 'Global Ozone Monitoring Experiment' (GOME), which is essentially a scaled-down version of the SCIAMACHY instrument proposed for the European Polar Platform to be launched at the end of the century.

The inclusion of the GOME sensor in ERS-2 Programme was endorsed on the explicit understanding that:
- the sensor would be developed, tested, calibrated and integrated in the same time frame as the satellite and the other instruments would be rebuilt
- the resource demands of the sensor would have to be satisfied from the existing system margins, imposing stringent limitations on mass, power and data rate
- no major upgrades in the ERS Ground Segment would be needed, and the financial burden for the data-processing algorithms and software would be borne by scientific institutions and/or national agencies.

The limitations on resources have already led to drastic changes in the instrument concept, because at the Baseline Design Review held in February 1991 it became obvious that the power/energy demand exceeded the available margin. Instead of GOME having its own interface to the On-Board Computer (OBC) and to the Instrument Data Handling and Transmission (IDHT) system, it was decided to provide these functions via the existing interfaces of the Along-Track Scanning Radiometer (ATSR) instrument.

Scientific objectives

Ozone (O_3) is a tri-atomic form of oxygen, formed by hard ultraviolet radiation in the atmospheric layer between about 15 and 45 km altitude, the so-called 'stratosphere'. It absorbs radiation in the spectral region between 240 and 310 nm, preventing these harmful rays from reaching the ground in large quantities. This naturally protective atmospheric layer is now being threatened by human activities, in particular by the steady release of chlorfluorocarbons (CFCs) into the atmosphere. The accumulated anthropogenic effects on stratospheric ozone are believed to be causing a steady depletion of the ozone layer by approximately 0.3 % per year.

The chemistry of the stratosphere is very complex. The hard ultraviolet radiation causes the breakup of many of the available species into reactive fragments, which lead to a multitude of possible reactions. Normally, the rates of these reactions depend not only on the nature of the species, but also on local pressure, temperature, radiative fluxes in the different wavelength regions, vertical and horizontal transport processes, etc. Thus, in order to understand the ozone chemistry fully, it is not sufficient just to measure the ozone; one must also monitor the abundances of many other species, including very

reactive intermediate species occurring in only very low concentrations

Reflecting this need, GOME is intended to measure other species as well as to observe aerosols and polar stratospheric clouds which play significant roles in the heterogeneous processes associated with ozone chemistry. It is hoped that some of these species may be observed in the troposphere, another part of the atmosphere believed to be affected by man's activities. However, the presence of clouds may make this difficult.

For this GOME will exploit spectroscopy, which is a viable technique for observing trace species in the atmosphere. Sunlight, reflected by the ground surface and scattered within the different atmospheric layers, carries the absorption signatures of the absorbing species (Figs. 1 & 2). The GOME instrument is designed to collect this light over the entire wavelength region from 240 to 790 nm, in which not only ozone, but also a number of other atmospheric species absorb. In addition to the classical backscatter technique, the GOME instrument exploits the novel technique of 'Differential Absorption Spectroscopy' (DOAS)*.

Satellite mission and instrument accommodation

Like its predecessor ERS-1, ERS-2 will fly in a Sun-synchronous polar orbit with an inclination of 98°, with a mean altitude of 780 km and a local time of 10.30 h for the equator crossing on the descending node. This results in an orbital period of approximately 100 min and a ground speed for the subsatellite point of 7 km/s.

The GOME instrument's instantaneous field of view has been chosen to be 40 km x 2 km, or 2.8° x 0.14°. Via the

* Developed by U. Platt (Heidelberg, FRG).

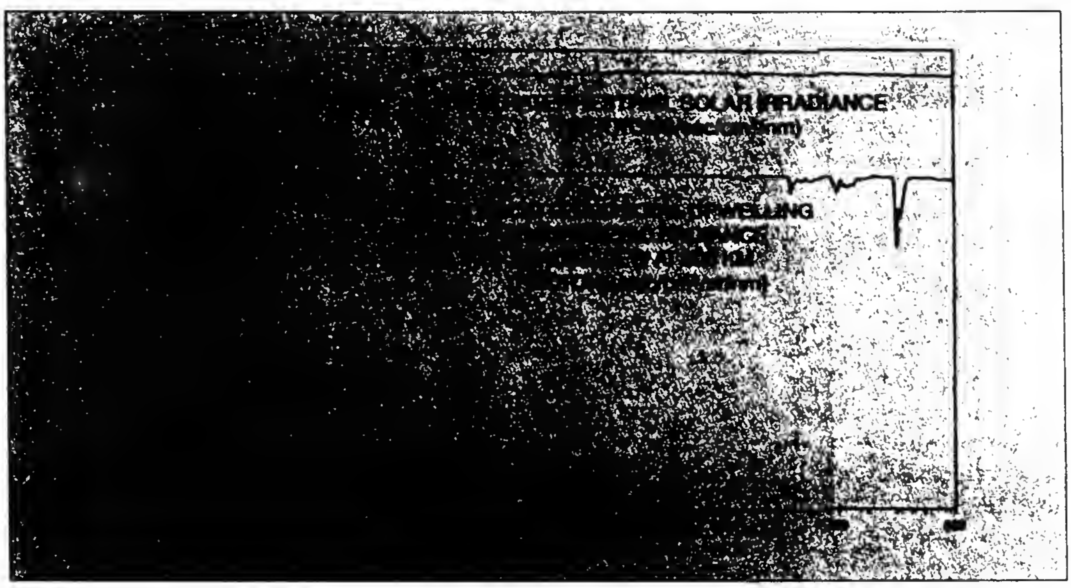


Figure 1. LOWTRAN simulation of spectral radiances at the top of the atmosphere in the wavelength range of the GOME instrument, i.e. 240–790 nm

Figure 2. Ozone absorption cross-sections in the wavelength range of the GOME instrument

Figure 3. Artist's impression of the GOME instrument's scanning geometry

movement of the instrument's scanning mirror, this instantaneous field of view can be scanned across the satellite's track. With a ±31° scan, global coverage can be achieved within 3 days, except for a gap of approximately 4° around both poles. To overcome this limitation, a special pole-viewing mode has been included (Figs. 3 & 4a,b).

The GOME instrument is mounted externally, on the surface of the payload module facing in the flight direction (i.e. the −Y face), with a clear field of view in the nadir direction (Fig. 5). It is thermally decoupled from the spacecraft structure as far as possible.

Photon flux computations show that for the visible/near-infrared channels, a good signal-to-noise ratio can be achieved with a 1.5 s integration time on the detector. The time for one forward scan has therefore been set to 4.5 s. For the flyback of the scanning mirror, another 1.5 s have been allowed, resulting in the scan pattern shown in Figure 6, with a ground pixel size of 320 km x 40 km.

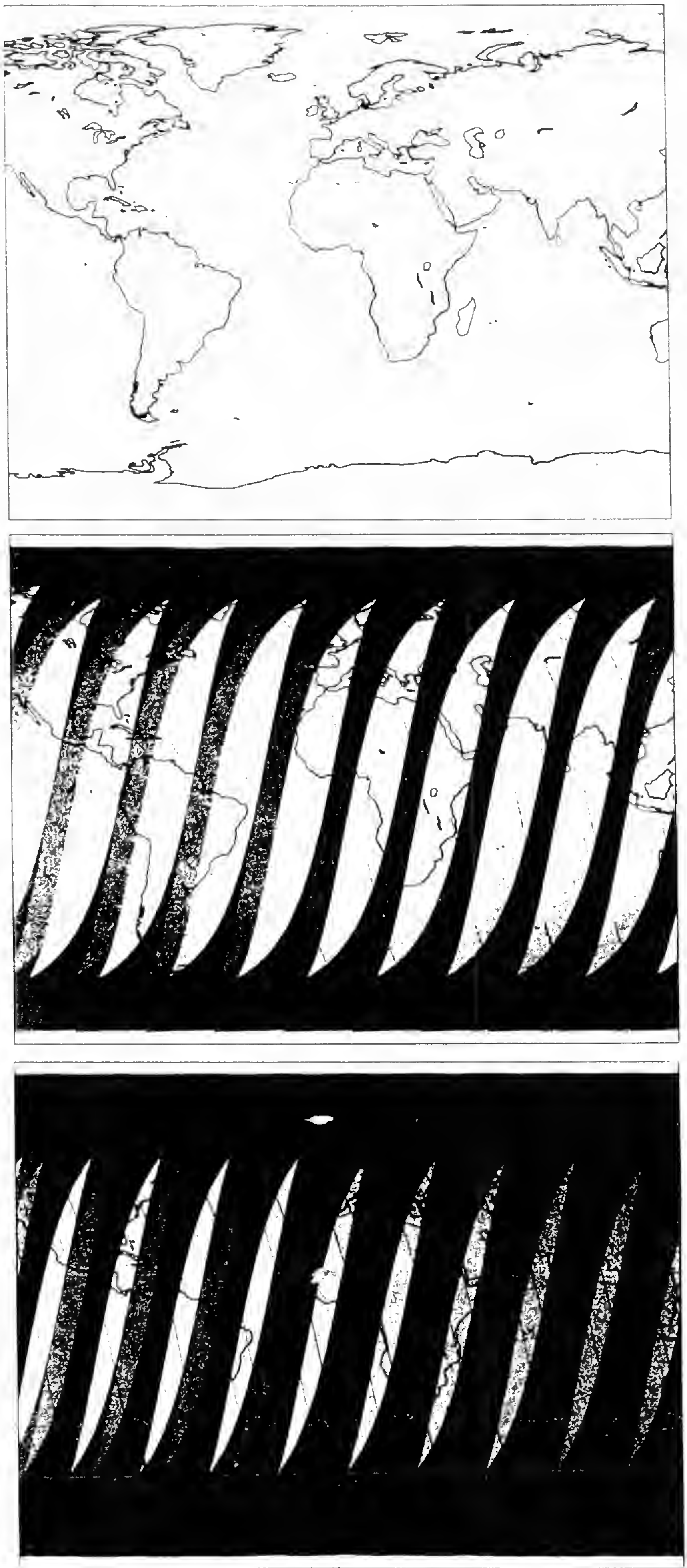
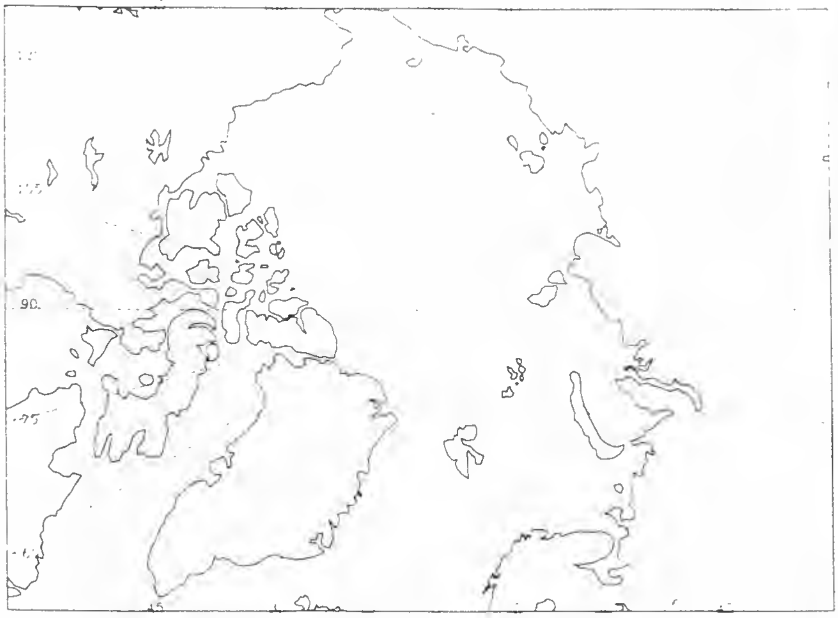
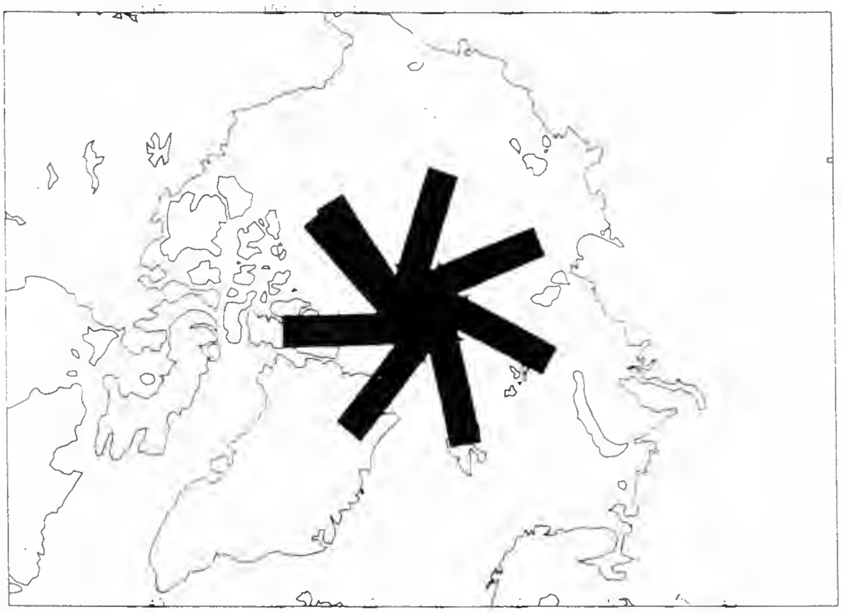


Figure 4a. Three-day coverage map for GOME





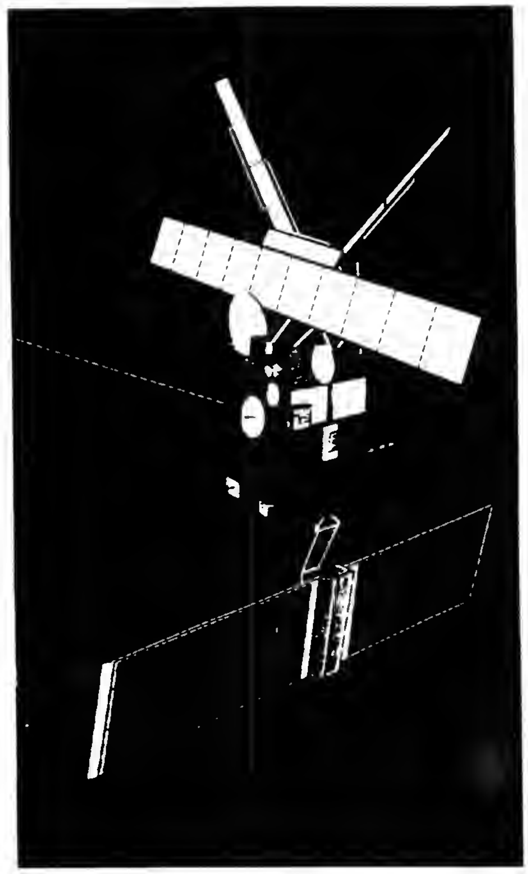


Figure 5. Artist's impression of the GOME instrument aboard ERS-2

The instrument's design

As a general principle, the GOME instrument collects light arriving from the Sun-illuminated Earth's atmosphere and decomposes it into its spectral components. In order to provide both the required spectral coverage from 240 to 790 nm and a good spectral resolution of 0.2–0.4 nm, this decomposition is done in two steps: first by a quartz pre-disperser prism, in which the light is split into four different channels. Each of these channels contains a grating as second dispersing element, and a 1024-pixel silicon array detector (the integration times on the chip can be multiples of 93.75 ms, with 1.5 s for the visible and 30 s for the ultraviolet being the default values).

The entire GOME instrument can be broken down into the following functional blocks:
- the spectrometer
- the four Focal-Plane Assemblies (FPAs)
- the Calibration Unit
- the scan unit with the scanning mechanism and the scan unit electronics (SEU) assembly

Figure 4b. Three-day coverage map for GOME

- the Polarisation Measurement Device (PMD)
- the Digital Data Handling Unit (DDHU)
- the optical bench structure
- the thermal control hardware.

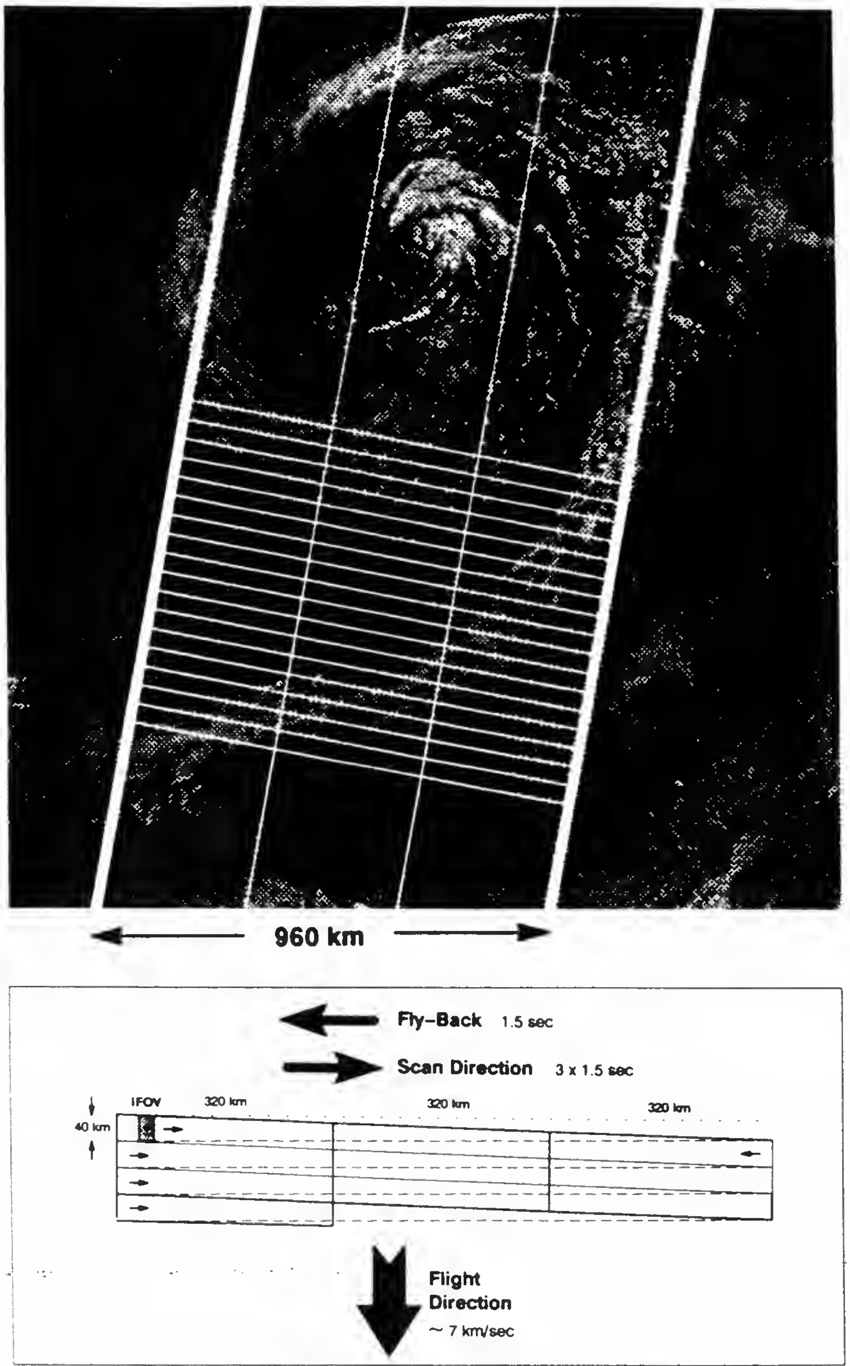


Figure 6. GOME scan pattern (graphic courtesy of DLR, Oberpfaffenhofen)

Table 1. Key optics performance parameters

Band	Wavelength range (nm)	Grating (l/mm)	Pixel resolution (nm)	Spectral resolution (nm)
1A	240–268	3600	0 11	0 22
1B	268–295			
2A	290–312	2400	0 12	0 24
2B	312–405			
3	400–605	1200	0 2	0 4
4	590–790	1200	0 2	0 4

Spectrometer optics

In the spectrometer optics, shown schematically in Figure 7, the light reflected off the scanning mirror is focussed by an anamorphic telescope such that the shape of the focus matches the entrance slit of the spectrometer (dimensions 10 mm x 100 µm. After the slit, the light is collimated by an off-axis parabolic mirror. It then strikes the quartz pre-disperser prism, causing a moderately wavelength dispersed beam. Another prism acts as channel separator: the upper edge of this prism reaches into the wavelength-dispersed beam, letting the longer wavelengths pass, reflecting the wavelength range 290–405 nm into Channel 2 by means of a dielectric reflecting coating, and guiding the wavelength range 240–295 nm internal to the prism into Channel 1. The unaffected wavelength range of 405–790 nm is then split up by a dichroic beam splitter into Channels 3 (400–605 nm) and 4 (590–790 nm).

Each individual channel consists of an off-axis parabola, a grating, and an objective with f-numbers of 2 (Channels 1 and 2) and 3 (Channels 3 and 4), finally focussing the light onto the detectors contained in their respective Focal-Plane Assemblies.

The most critical optical elements in the optical chain are the diffraction gratings, which have to provide both a high efficiency in the first diffraction order and a very low level of stray light and ghosting. Because of the criticality of the gratings for the final performance of the instrument, two parallel development programmes are under way, at the firms of Jobin-Yvon in France and Carl Zeiss in Germany. Some of the key performance requirements for the optics are summarised in Table 1.

Focal-Plane Assemblies

The FPAs are made from titanium and have a sealed quartz window at the side where they are flanged to the respective objective tubes. The rear side of the FPA, the so-called 'pin-plate', is a titanium plate provided with electrically isolated, vacuum-tight feed-throughs for the electrical connections to the detector. This is a Reticon RL 1024 SR random-access diode array detector with 1024 pixels, each pixel measuring 25 µm in the dispersion direction and 2.5 mm in the along-slit direction. Each diode is randomly accessible by an address bus and can be read out individually.

In the GOME instrument, the detectors of Channels 1 and 2 are split into several

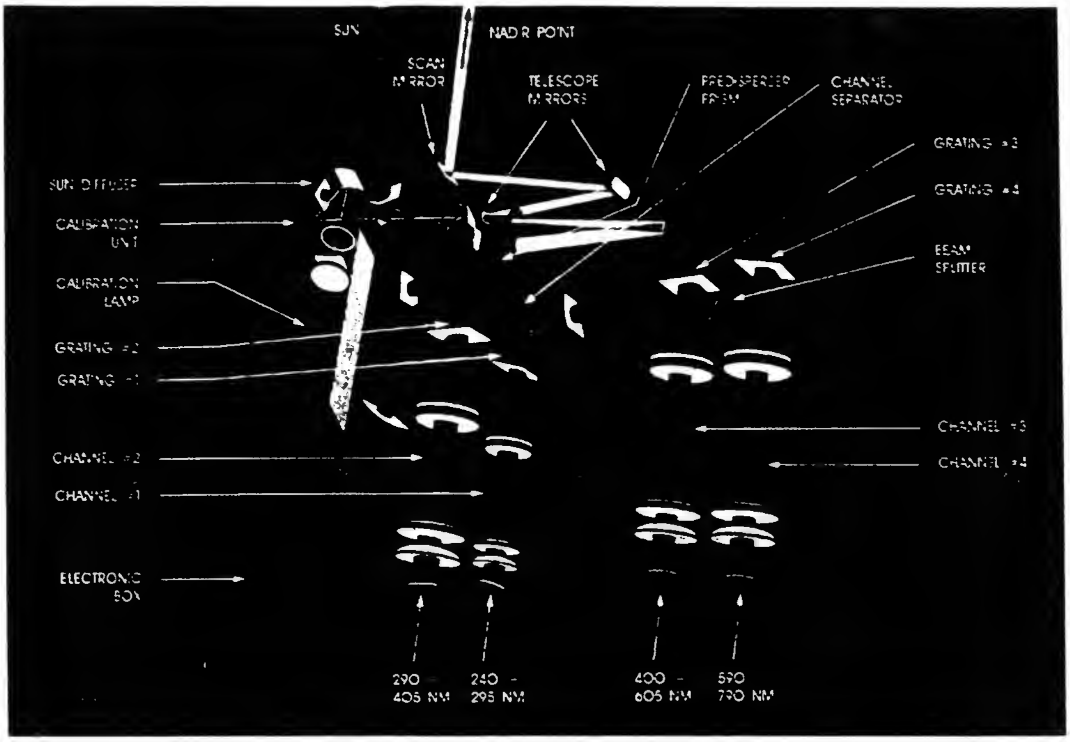


Figure 7. Spectrometer optics

bands, the integration times of which may be varied individually. The Reticon detector chip is shown in Figure 8. The detectors are glued onto two-stage Peltier coolers, which reduce their temperature to −40°C to keep the dark current of the photodiodes sufficiently low. The hot side of the Peltier coolers is glued (in the engineering model), respectively brazed (in the flight model), to a copper bar, extending through the pin-plate. Outside the FPA, this copper bar is connected via flexible connections and heat pipes to the main radiator. The tips carrying the Peltier coolers and detectors are tilted between 1.6° and 9.5°, to compensate for chromatic aberration.

At the back side of the FPA, the Front-End Electronics (FEE) are mounted on a printed-circuit board. They are based on a charge amplifier implemented with a low-noise amplifier and a dual-FET input stage. The output of the FEE is fed to the Digital Data Handling Unit (DDHU), where it is further processed and digitised.

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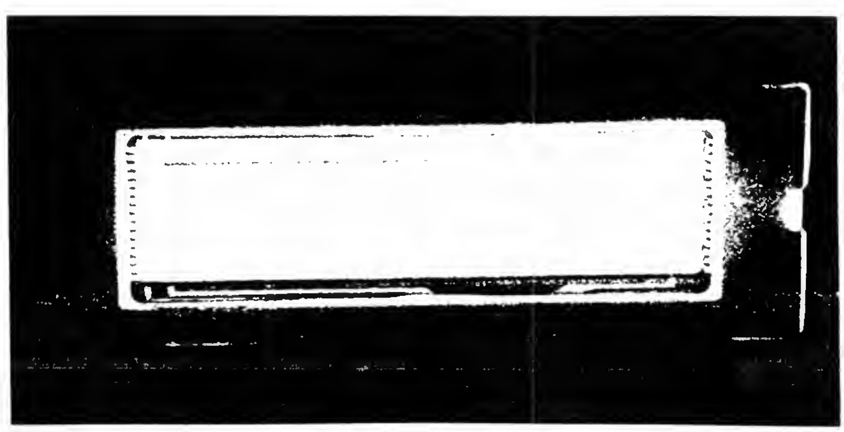

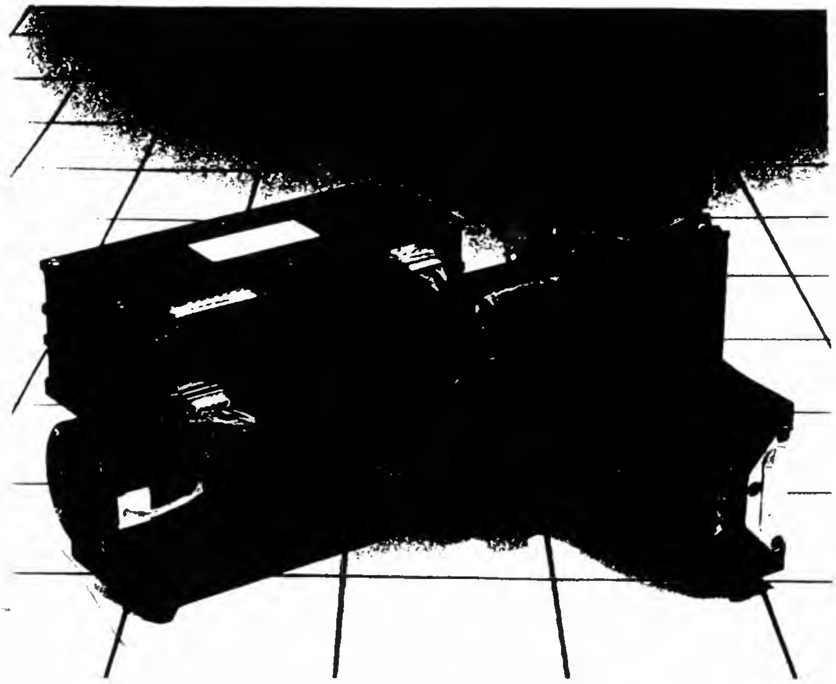

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Introduction

In 1989, ESA decided to continue the ERS Programme beyond the expected lifetime of the ERS-1 satellite by approving the building and launch of the ERS-2 satellite. To provide the necessary continuity to the observations started by the instruments of ERS-1, ERS-2 is essentially a carbon-copy of the ERS-1 satellite. It was recognised, however, that there is an urgent need to investigate the composition and dynamic behaviour of the Earth's atmosphere. The ERS-2 Programme approval therefore included an experimental sensor for atmospheric research, the 'Global Ozone Monitoring Experiment' (GOME), which is essentially a scaled-down version of the SCIAMACHY instrument proposed for the European Polar Platform to be launched at the end of the century.

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Ozone (O_3) is a tri-atomic form of oxygen, formed by hard ultraviolet radiation in the atmospheric layer between about 15 and 45 km altitude, the so-called 'stratosphere'. It absorbs radiation in the spectral region between 240 and 310 nm, preventing these harmful rays from reaching the ground in large quantities. This naturally protective atmospheric layer is now being threatened by human activities, in particular by the steady release of chlorfluorocarbons (CFCs) into the atmosphere. The accumulated anthropogenic effects on stratospheric ozone are believed to be causing a steady depletion of the ozone layer by approximately 0.3 % per year.

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Like its predecessor ERS-1, ERS-2 will fly in a Sun-synchronous polar orbit with an inclination of 98°, with a mean altitude of 780 km and a local time of 10.30 h for the equator crossing on the descending node. This results in an orbital period of approximately 100 min and a ground speed for the subsatellite point of 7 km/s.

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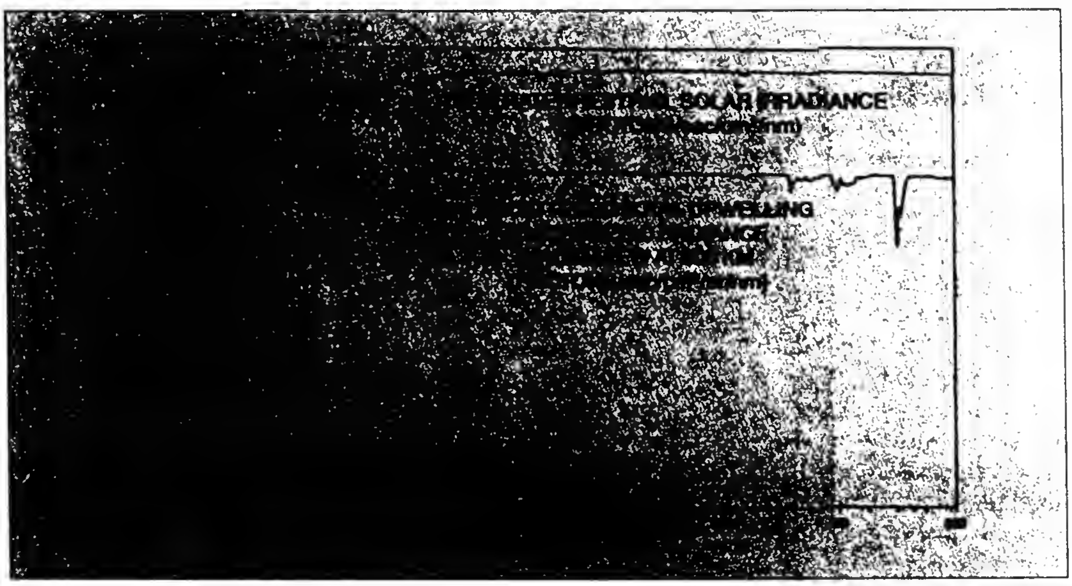


Figure 1. LOWTRAN simulation of spectral radiances at the top of the atmosphere in the wavelength range of the GOME instrument, i.e. 240–790 nm

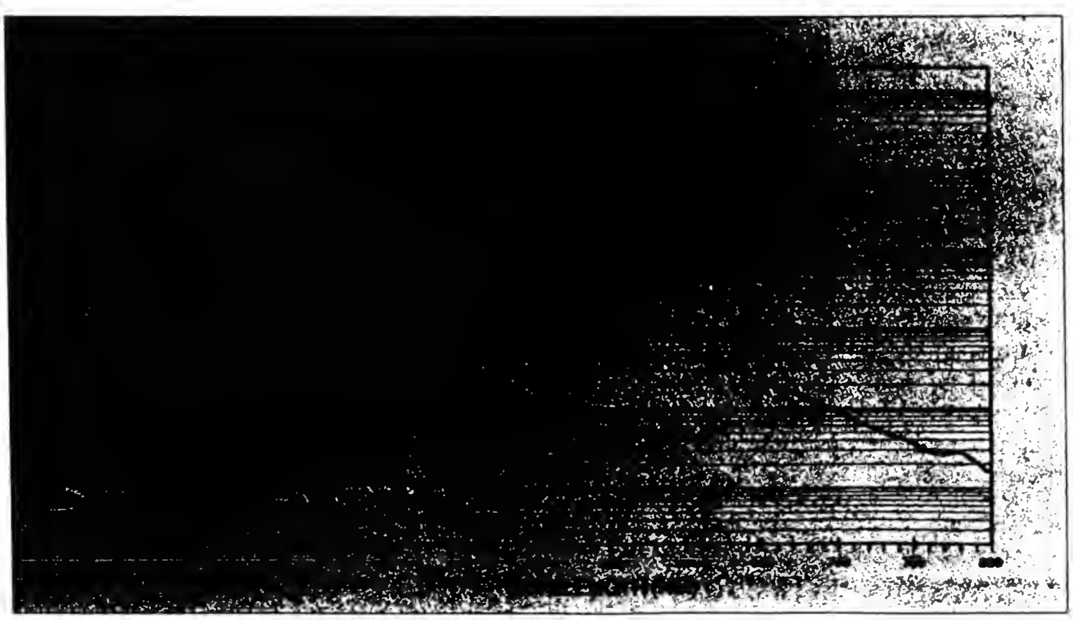


Figure 2. Ozone absorption cross-sections in the wavelength range of the GOME instrument

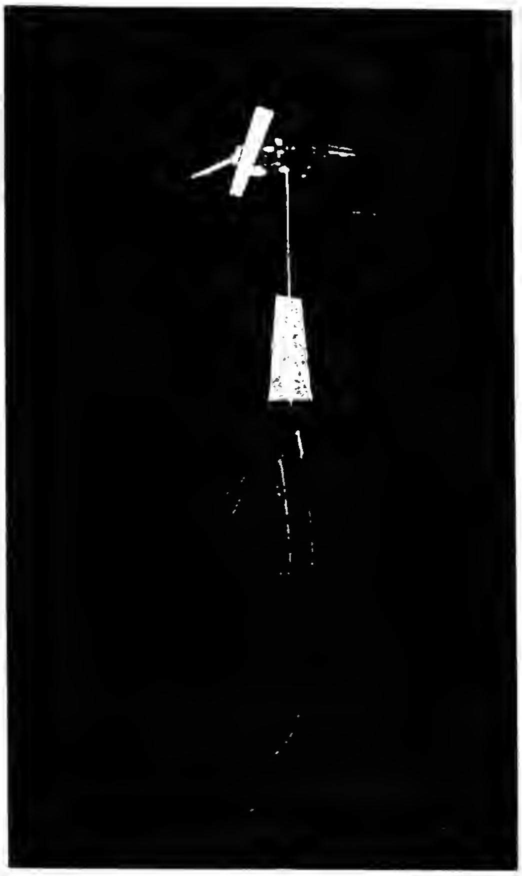
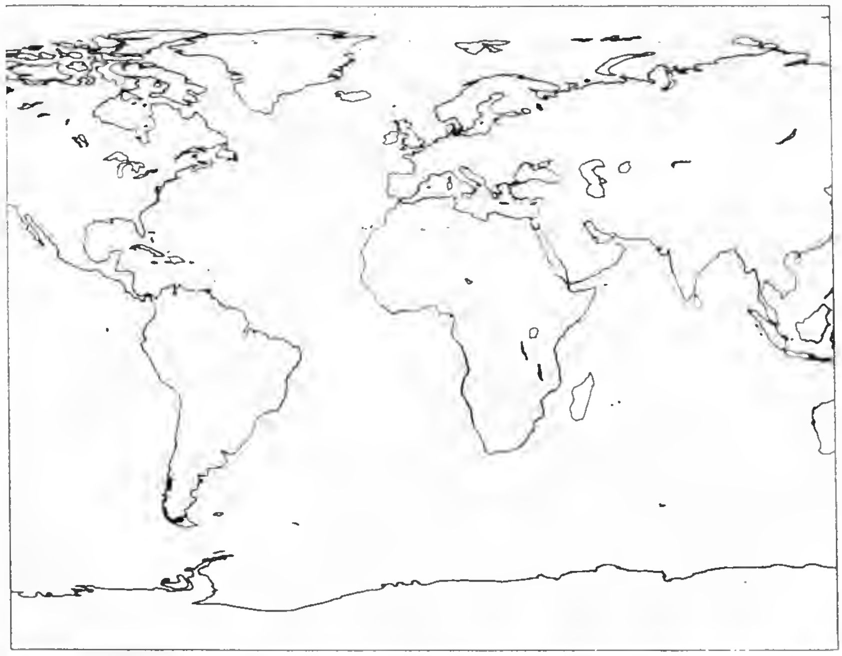


Figure 3. Artist's impression of the GOME instrument's scanning geometry

movement of the instrument's scanning mirror, this instantaneous field of view can be scanned across the satellite's track. With a ±31° scan, global coverage can be achieved within 3 days, except for a gap of approximately 4° around both poles. To overcome this limitation, a special pole-viewing mode has been included (Figs. 3 & 4a,b).

The GOME instrument is mounted externally, on the surface of the payload module facing in the flight direction (i.e. the −Y face), with a clear field of view in the nadir direction (Fig. 5). It is thermally decoupled from the spacecraft structure as far as possible.

Photon flux computations show that for the visible/near-infrared channels, a good signal-to-noise ratio can be achieved with a 1.5 s integration time on the detector. The time for one forward scan has therefore been set to 4.5 s. For the flyback of the scanning mirror, another 1.5 s have been allowed, resulting in the scan pattern shown in Figure 6, with a ground pixel size of 320 km x 40 km.



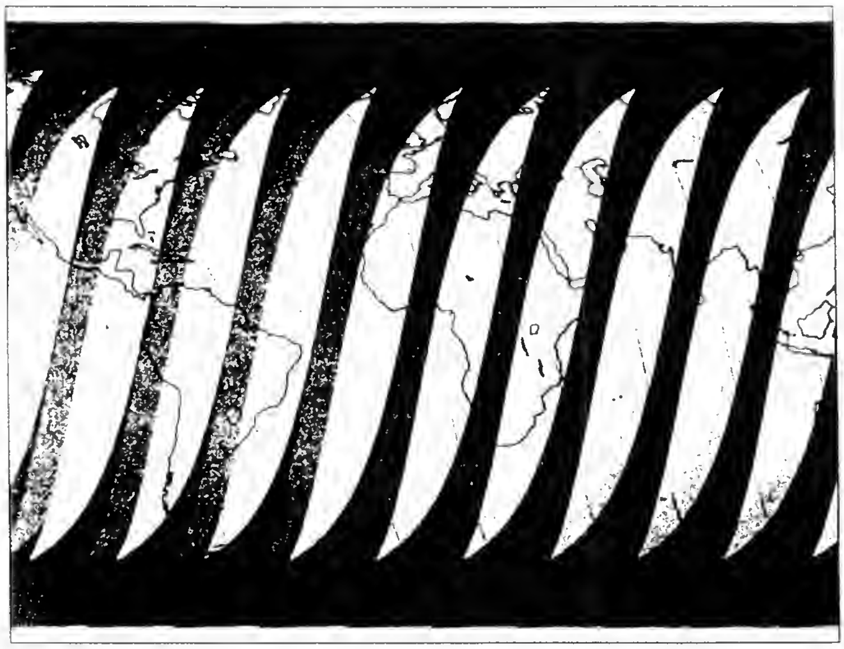
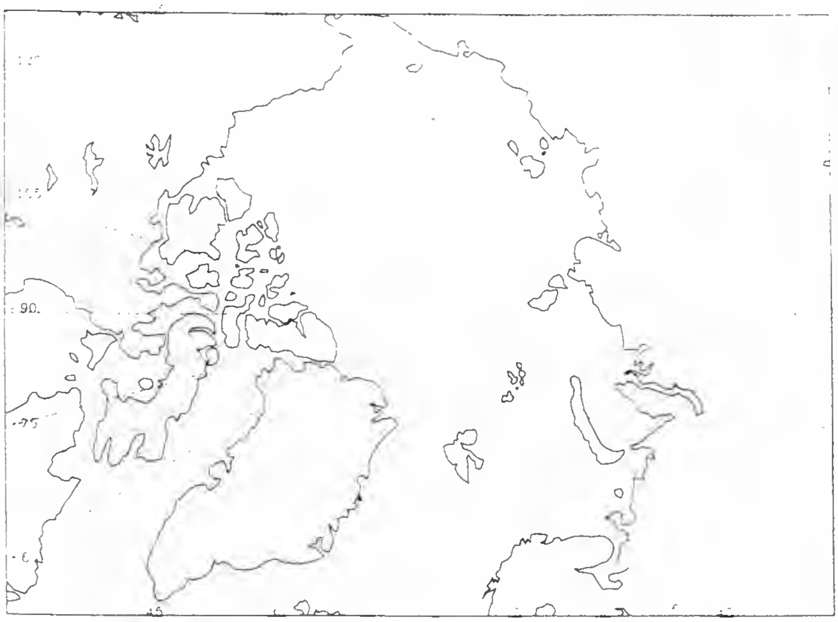


Figure 4a. Three-day coverage map for GOME



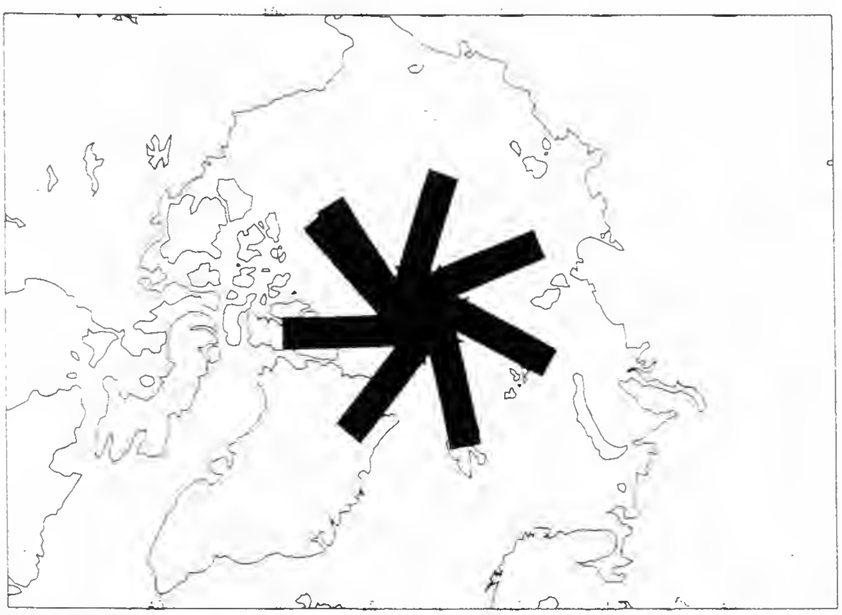


Figure 4b. Three-day coverage map for GOME

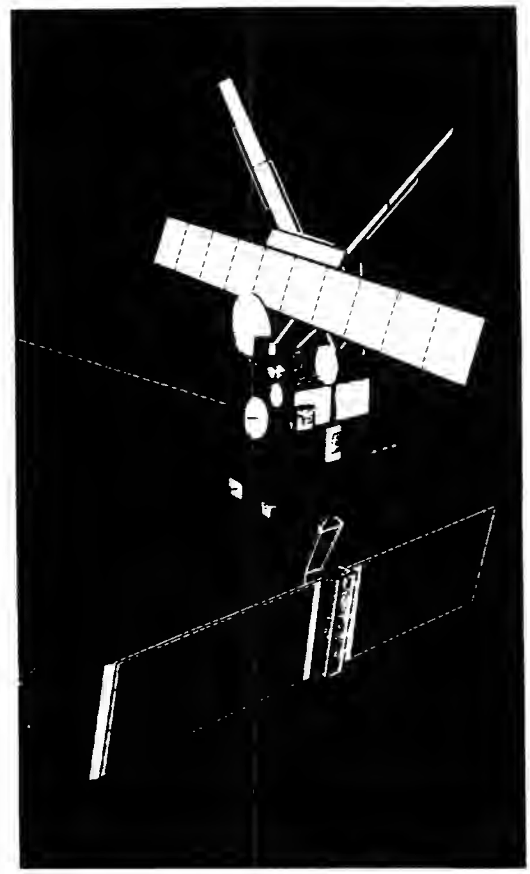


Figure 5. Artist's impression of the GOME instrument aboard ERS-2

The instrument's design

As a general principle, the GOME instrument collects light arriving from the Sun-illuminated Earth's atmosphere and decomposes it into its spectral components. In order to provide both the required spectral coverage from 240 to 790 nm and a good spectral resolution of 0.2–0.4 nm, this decomposition is done in two steps: first by a quartz pre-disperser prism, in which the light is split into four different channels. Each of these channels contains a grating as second dispersing element, and a 1024-pixel silicon array detector (the integration times on the chip can be multiples of 93.75 ms, with 1.5 s for the visible and 30 s for the ultraviolet being the default values).

The entire GOME instrument can be broken down into the following functional blocks:
- the spectrometer
- the four Focal-Plane Assemblies (FPAs)
- the Calibration Unit
- the scan unit with the scanning mechanism and the scan unit electronics (SEU) assembly

- the Polarisation Measurement Device (PMD)
- the Digital Data Handling Unit (DDHU)
- the optical bench structure
- the thermal control hardware.

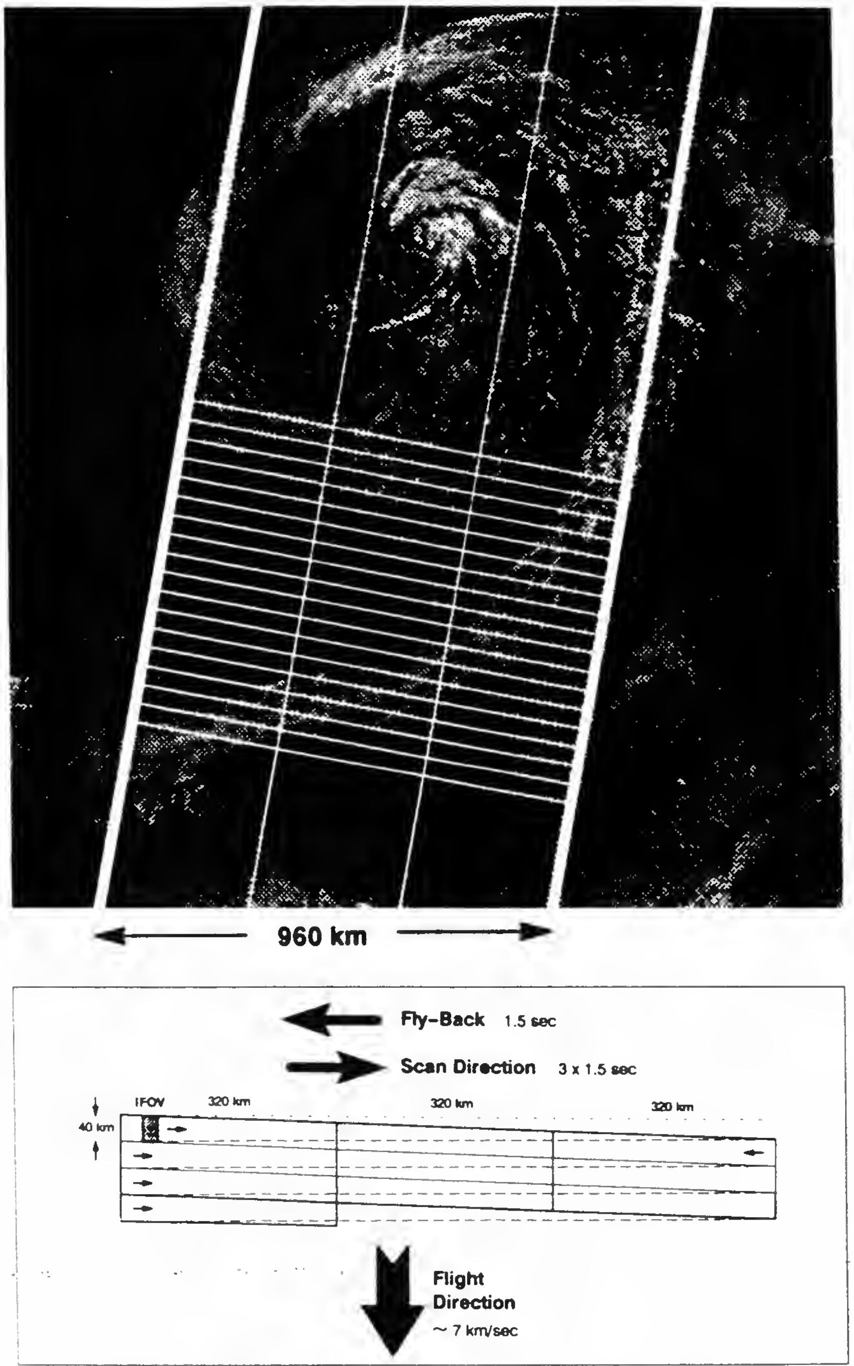


Figure 6. GOME scan pattern (graphic courtesy of DLR, Oberpfaffenhofen)

Table 1. Key optics performance parameters

Band	Wavelength range (nm)	Grating (l/mm)	Pixel resolution (nm)	Spectral resolution (nm)
1A	240–268	3600	0.11	0.22
1B	268–295			
2A	290–312	2400	0.12	0.24
2B	312–405			
3	400–605	1200	0.2	0.4
4	590–790	1200	0.2	0.4

Spectrometer optics

In the spectrometer optics, shown schematically in Figure 7, the light reflected off the scanning mirror is focussed by an anamorphic telescope such that the shape of the focus matches the entrance slit of the spectrometer (dimensions 10 mm x 100 µm. After the slit, the light is collimated by an off-axis parabolic mirror. It then strikes the quartz pre-disperser prism, causing a moderately wavelength dispersed beam. Another prism acts as channel separator: the upper edge of this prism reaches into the wavelength-dispersed beam, letting the longer wavelengths pass, reflecting the wavelength range 290–405 nm into Channel 2 by means of a dielectric reflecting coating, and guiding the wavelength range 240–295 nm internal to the prism into Channel 1. The unaffected wavelength range of 405–790 nm is then split up by a dichroic beam splitter into Channels 3 (400–605 nm) and 4 (590–790 nm).

Each individual channel consists of an off-axis parabola, a grating, and an objective with f-numbers of 2 (Channels 1 and 2) and 3 (Channels 3 and 4), finally focussing the light onto the detectors contained in their respective Focal-Plane Assemblies.

The most critical optical elements in the optical chain are the diffraction gratings, which have to provide both a high efficiency in the first diffraction order and a very low level of stray light and ghosting. Because of the criticality of the gratings for the final performance of the instrument, two parallel development programmes are under way, at the firms of Jobin-Yvon in France and Carl Zeiss in Germany. Some of the key performance requirements for the optics are summarised in Table 1.

Focal-Plane Assemblies

The FPAs are made from titanium and have a sealed quartz window at the side where they are flanged to the respective objective tubes. The rear side of the FPA, the so-called 'pin-plate', is a titanium plate provided with electrically isolated, vacuum-tight feed-throughs for the electrical connections to the detector. This is a Reticon RL 1024 SR random-access diode array detector with 1024 pixels, each pixel measuring 25 µm in the dispersion direction and 2.5 mm in the along-slit direction. Each diode is randomly accessible by an address bus and can be read out individually.

In the GOME instrument, the detectors of Channels 1 and 2 are split into several

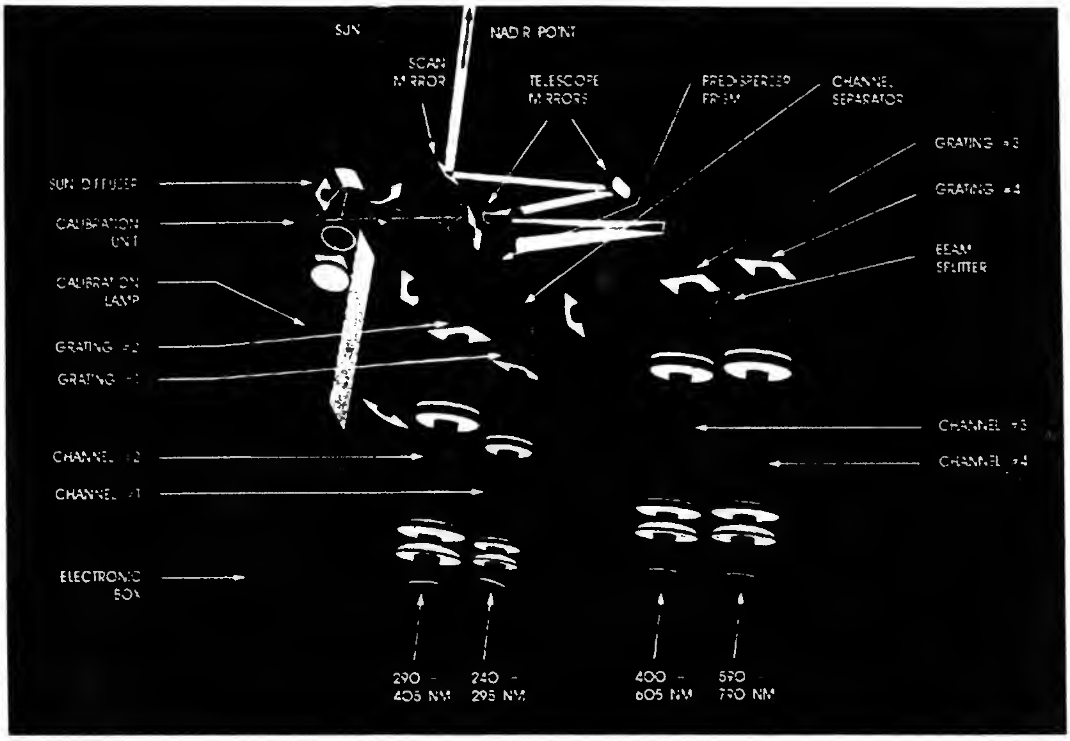


Figure 7. Spectrometer optics

bands, the integration times of which may be varied individually. The Reticon detector chip is shown in Figure 8. The detectors are glued onto two-stage Peltier coolers, which reduce their temperature to −40°C to keep the dark current of the photodiodes sufficiently low. The hot side of the Peltier coolers is glued (in the engineering model), respectively brazed (in the flight model), to a copper bar, extending through the pin-plate. Outside the FPA, this copper bar is connected via flexible connections and heat pipes to the main radiator. The tips carrying the Peltier coolers and detectors are tilted between 1.6° and 9.5° to compensate for chromatic aberration.

At the back side of the FPA, the Front-End Electronics (FEE) are mounted on a printed-circuit board. They are based on a charge amplifier implemented with a low-noise amplifier and a dual-FET input stage. The output of the FEE is fed to the Digital Data Handling Unit (DDHU), where it is further processed and digitised.

During ground operations, the FPAs can be either evacuated, or filled with dry nitrogen to avoid moisture freezing out on the cooled detectors. In addition, the polarity of the Peltier elements can be inverted to heat the detectors to +80° to drive off possible contaminants and to anneal radiation effects. Once in orbit, the FPAs are exposed to the vacuum of space by a burst membrane, which is designed to open during the launch phase.

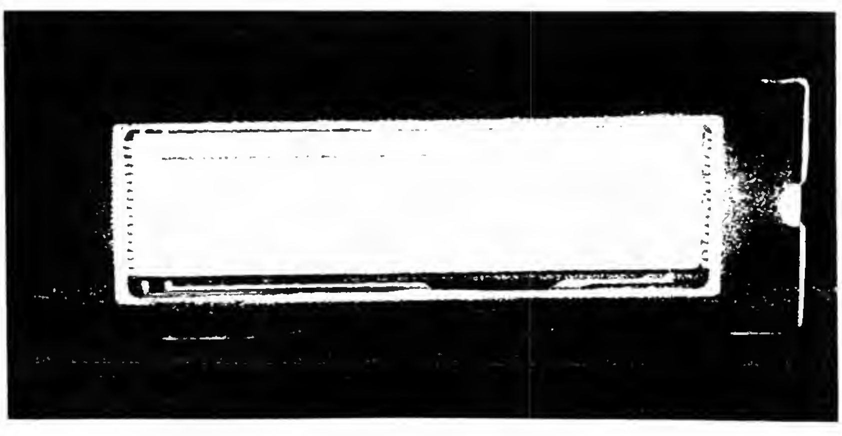
Calibration unit

In order to support the DOAS technique, one would like to have a wavelength stability of 1/100 th of a pixel. This is not achievable with a passive thermal design in such a power-limited situation. Instead, wavelength position on the detector pixels versus orbital temperature will be mapped by means of a hollow-cathode lamp (Pt-Cr-Ne) which provides a sufficient number of sharp lines in all wavelength regions.

For the radiometric calibration, the Sun will be used as the source. Because of the orbital and scanner geometry, which prevents direct viewing of the Sun via the scanning mirror, and because its high intensity would lead (even with the shortest possible integration time) to detector saturation, the Sun is viewed via a diffuser plate accommodated in the calibration unit (Fig. 9).

Previous NASA experience has shown that the diffuser is subject to degradation during its periods of exposure. Precautions are therefore taken by having:

Figure 8. Reticon RL1024SR detector chip



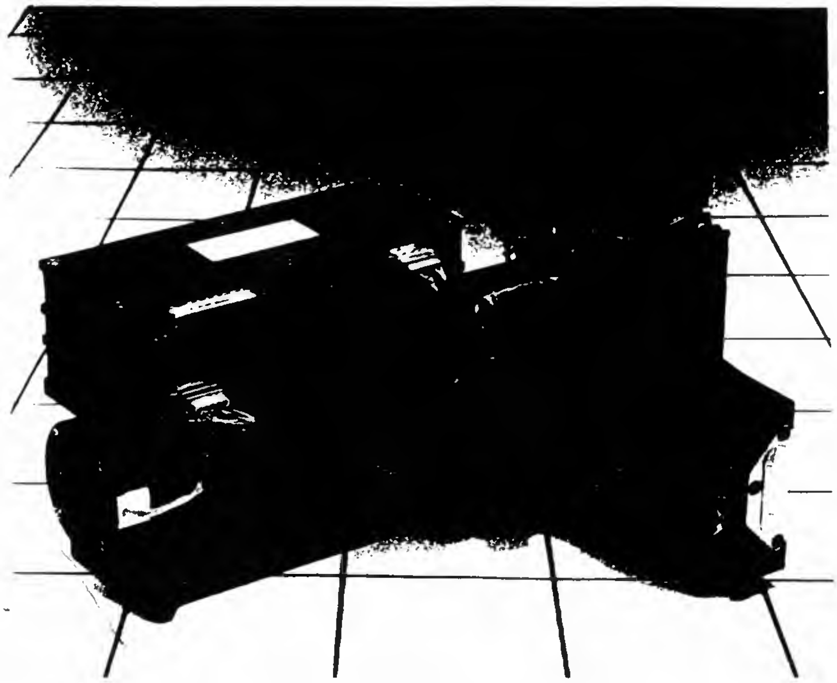


Figure 9. Calibration unit

- a mesh in front of the diffuser, attenuating the incoming light level and largely protecting the diffuser
- a shutter mechanism that opens only during Sun calibration and protects the diffuser during the remaining mission phases
- the possibility to view the calibration lamp via the diffuser, thereby having a means to monitor possible degradation, at least at those wavelengths provided by the lamp

Scanning unit

The scanning unit consists of two separate assemblies, the Scan Mechanism (SM) and the Scan Unit Electronics Assembly (SUEA). The scan mechanism is located on the optical bench, with its rotation axis aligned with the satellite's flight direction. The axis carries a glued-on aluminium-coated mirror, which can be heated from the rear to drive off possible contaminants, if necessary.

A brushless DC motor actuates the scanner, the position of which is sensed by a resolver. The rotating part of the resolver, the mirror heater and the temperature sensor are connected to the static part via a flexible printed-circuit connection. The angular range of the scanner is limited to −63.8 to +192.2° with respect to nadir (0°) by software and end stops.

The rotation axis is supported by two spring-preloaded angular contact bearings, the balls of which are ion-plated with lead and the races are made of lead bronze. All structural parts (housing, pivot, etc.) are made from titanium

Polarisation measurement device

The incoming light from the Earth's atmosphere can be partially polarised. Because the instrument's responses to the two orthogonal linear polarisation directions are not equal, there is a need to monitor the polarisation of the incoming light.

In the pre-disperser prism, light is internally reflected at the Brewster angle. About 5 % of this light, polarised normal to the plane of incidence, leaks away at this surface. This light is collected by an off-axis parabola, reflected by a mirror out of the plane of the optical bench, and then sensed by a custom-made photodiode array.

Because the device is not temperature-controlled, it is subject to drifts. To keep the impact of changing temperatures to a minimum, a second array of photodiodes with the same geometry, but not exposed to light, will be used to compensate for the dark current and its variability with temperature.

The measured signals are acquired by the DDHU, converted to digital signals, and included into the telemetry data (3 x 16 bit, 10.67 Hz).

Digital Data-Handling Electronics (DDHU)

The prime interface to the satellite's electrical subsystems is via the Digital Electronics Unit (DEU) of the Along-Track Scanning Radiometer (ATSR). Because the DEU now not only controls the ATSR's Infrared Radiometer (IRR) and Microwave Radiometer (MWR), but also GOME, a redundant DEU has been added, together with a DEU Switching Unit (DSU).

The DEU assumes all the normal functions of an Instrument Control Unit (ICU). Commands dedicated to GOME are expanded into a serial digital bit stream, initiating the appropriate actions within the DDHU. In the opposite direction, both housekeeping and scientific data are written by the DDHU into data buffers, from which they are requested by the DEU to be put into predefined fields of the ATSR S-band and X-band data streams.

Thermal-control hardware

The most critical aspect of the thermal control is the detector temperature, which is provided by the Peltier elements in each of the Focal-Plane Assemblies. The hot sides of the Peltiers are all connected, via copper bars and flexible connections, to a parallel pair of bent heat pipes, which end in the primary radiator exposed to deep space.

The DDHU and the scanning mirror electronics assembly have their own radiative surfaces for thermal control. The remainder of the instrument is wrapped in multi-layer insulation blankets. For cold non-operational phases, thermostat-controlled heater mats and resistors are directly powered from the payload's Power Distribution Unit.

Structure
All elements of the optics, mechanisms, electronics and thermal hardware are mounted on the optical bench, which is a nearly rectangular aluminium plate with stiffening ribs beneath. This optical bench is carried on four feet, one of which is round in cross-section and rather stiff. The other three are blade-shaped feet, with their flexing direction lying in the direction of the fixed foot. This prevents mechanical distortion of the optical alignment due to thermal expansion of the bench.

Beneath the optical bench, in the space between the ribs, the harness and the pipework for FPA evacuation are routed. An EMC shield protects the instrument from electromagnetic interference from the satellite's radars and communications system.

Operations
The GOME instrument has numerous measurement, calibration, and support modes. In particular, due to the varying light levels that will be experienced during each orbit, integration time settings will have to be adjusted frequently. In addition, once per day a Sun calibration has to be performed.

In order to limit the command traffic on the uplink, the DEU stores three different timelines, each of which can be activated automatically up to 16 times in sequence. One of these timelines is for normal operations, one for an orbit in which a Sun calibration is being performed, and one with a sidewards swath to cover the polar area (with the normal nadir-centred swath there would be a gap in coverage of about 4° around both poles).

About once per month, a wavelength mapping as function of the thermal variations will be performed with the wavelength calibration lamp. On these occasions a diffuser characterisation can also be carried out.

Lunar observations, which are restricted by the Sun–Moon–satellite scanner field-of-view geometry, will be performed whenever possible.

Data processing
GOME data will arrive together with the other 'low-bit-rate' data at the various ground stations to which the ERS tape recorders are downlinked. Extracted GOME data, together with orbit and attitude information, will then be shipped on Exabyte cassettes to the German Processing and Archiving Facility (D-PAF) in Oberpfaffenhofen. In a first processing step, the raw data will be corrected for instrument-induced errors and drifts, and provided with information on geo-location, Sun aspect angle, etc.

From these radiometrically and wavelength corrected geo-located spectra, the ozone total column amount, ozone vertical concentration profile, and data on aerosol loading and cloud cover can be retrieved. This will be done at distributed centres, according to the particular scientific expertise available. Time and budgets permitting, other atmospheric-constituent retrieval can be added to the range of data products generated. Finally, time and spatial averaging for long-term global-trend analyses is likely to be conducted (not yet specifically defined).

In addition to this off-line processing chain, some limited processing capabilities will also be installed at ESTEC, in order to evaluate the instrument performance after launch, optimise parameter settings and operating schemes, and to support possible scientific campaigns.

GOME should produce unique data as there will be no other instrument available on its time scale which duplicates its capabilities. The instrument fills a critical slot as far as future observing strategies are concerned, and GOME could well become the prototype for subsequent ozone-monitoring instruments. Its medium spectral resolution combined with a wide spectral range and absolute calibration is particularly important as it means that, in addition to applying the traditional backscatter approach, one can also use differential optical absorption spectroscopy to retrieve data with GOME.

Acknowledgements
We gratefully acknowledge the unfailing support of the GOME Science Team, headed by Prof. Dr. J. Burrows from the University of Bremen (D). Much of the work reported here has been done by the GOME Industrial Team, comprised of Officine Galileo (I), Laben (I), TPD/TNO (NL), Dornier (D) and the Rutherford Appleton Laboratory (UK), and BAe (UK) for the DEU modifications.

GOME: A New Instrument for ERS-2

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ERS Project Division, ESA Directorate for Observation of the Earth and Its Environment, ESTEC, Noordwijk, The Netherlands

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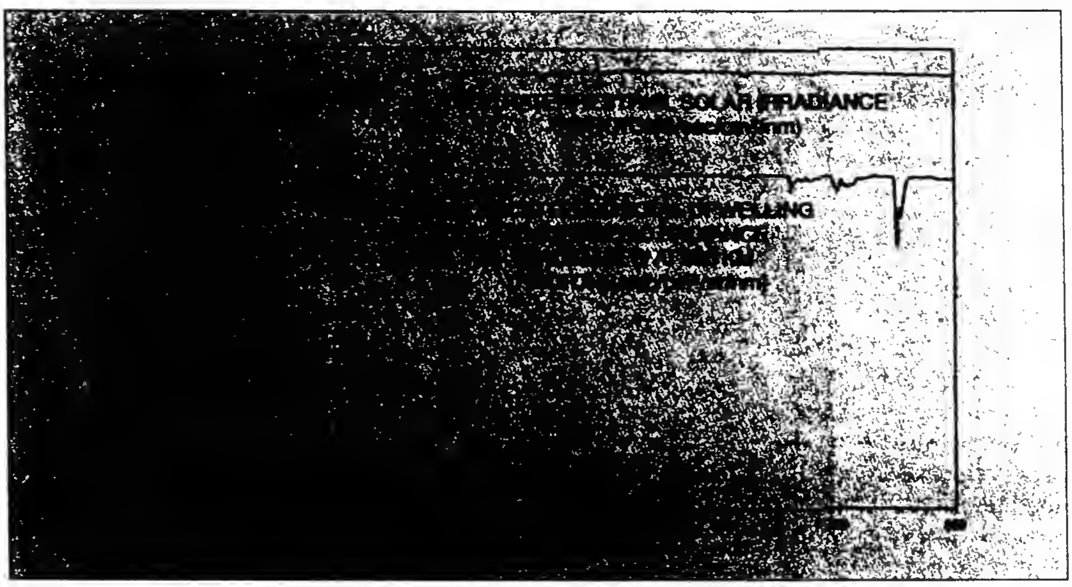

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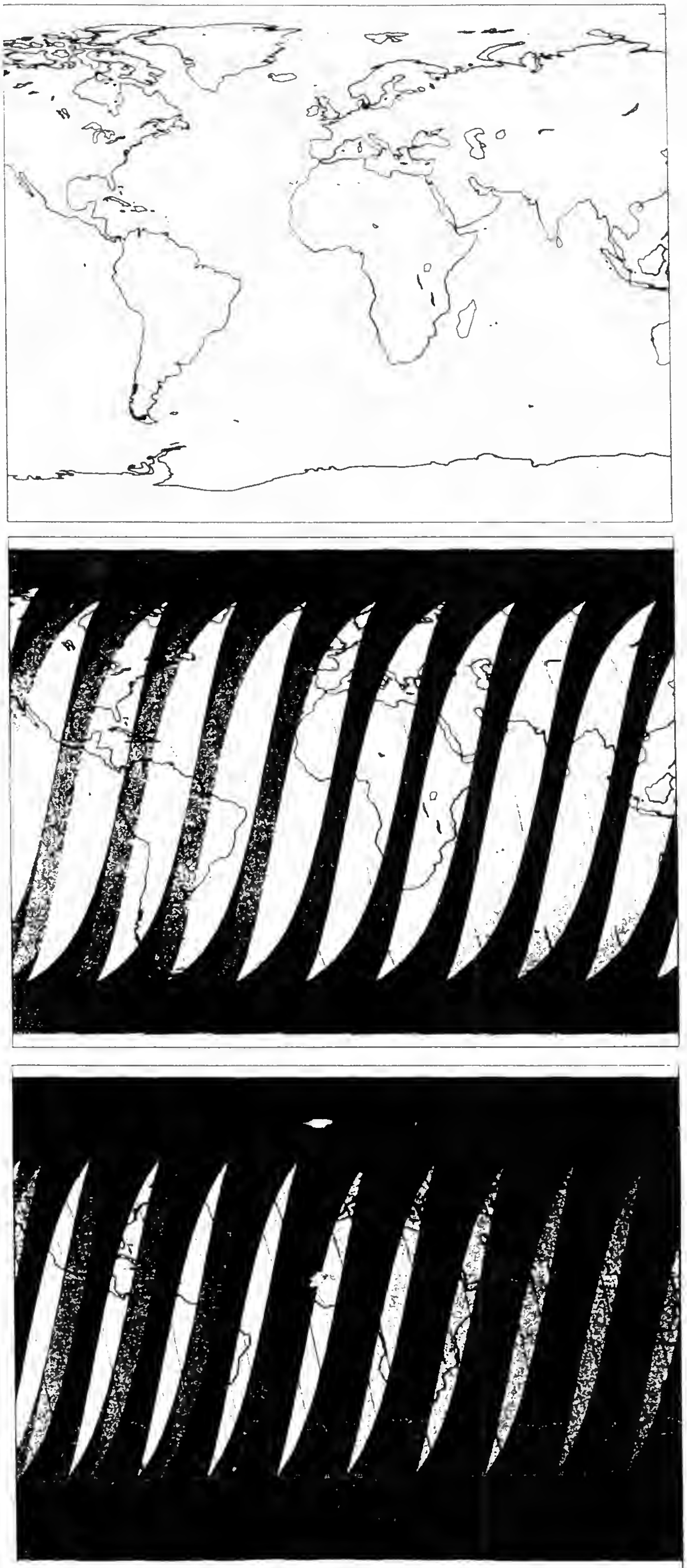

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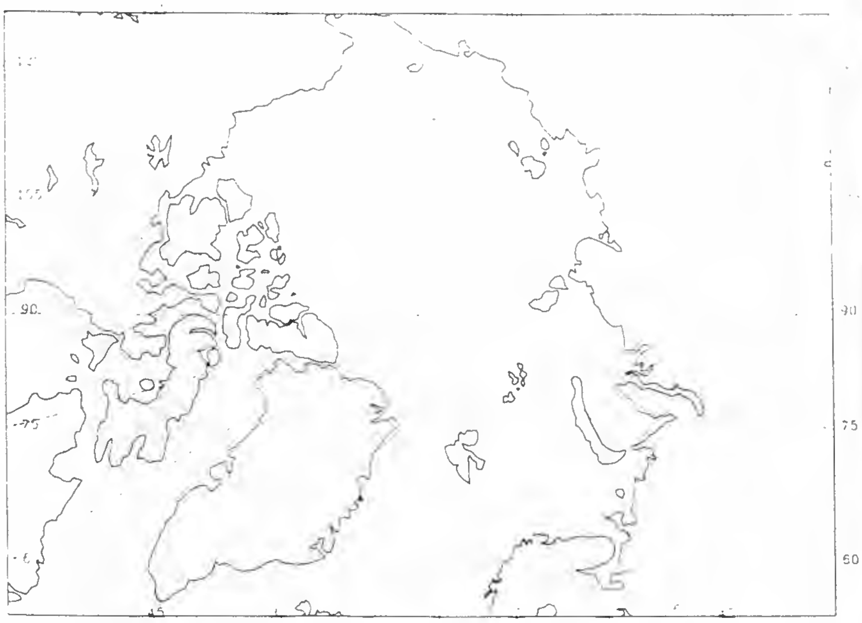

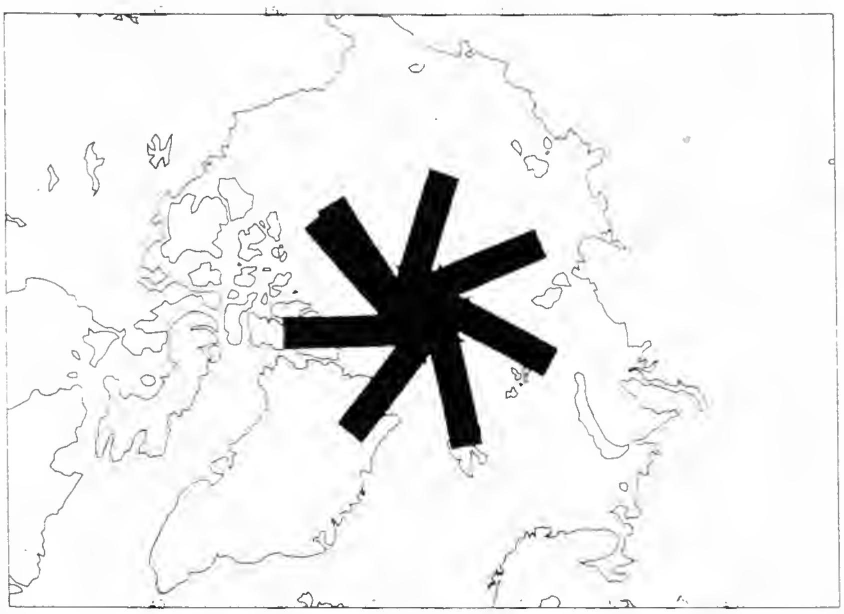

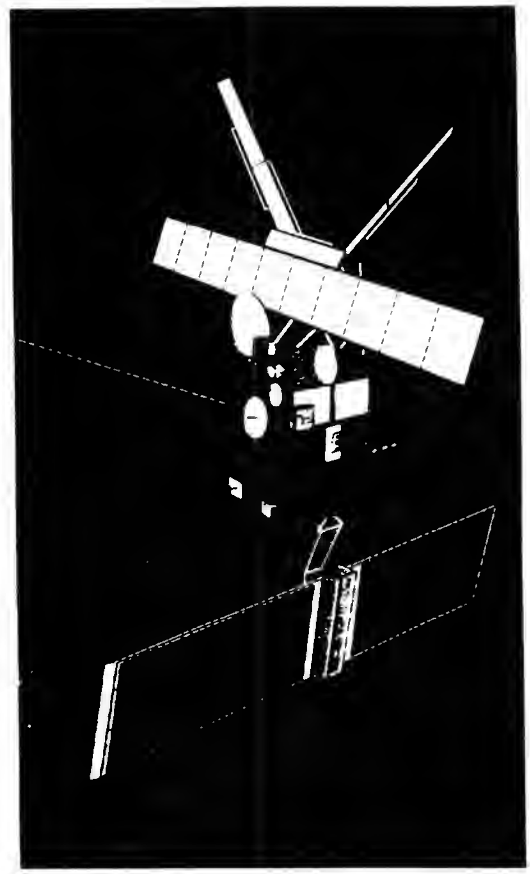

Figure 5. Artist's impression of the GOME instrument aboard ERS-2

The instrument's design

As a general principle, the GOME instrument collects light arriving from the Sun-illuminated Earth's atmosphere and decomposes it into its spectral components. In order to provide both the required spectral coverage from 240 to 790 nm and a good spectral resolution of 0.2–0.4 nm, this decomposition is done in two steps: first by a quartz pre-disperser prism, in which the light is split into four different channels. Each of these channels contains a grating as second dispersing element, and a 1024-pixel silicon array detector (the integration times on the chip can be multiples of 93.75 ms, with 1.5 s for the visible and 30 s for the ultraviolet being the default values)

The entire GOME instrument can be broken down into the following functional blocks:
- the spectrometer
- the four Focal-Plane Assemblies (FPAs)
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- the Digital Data Handling Unit (DDHU)
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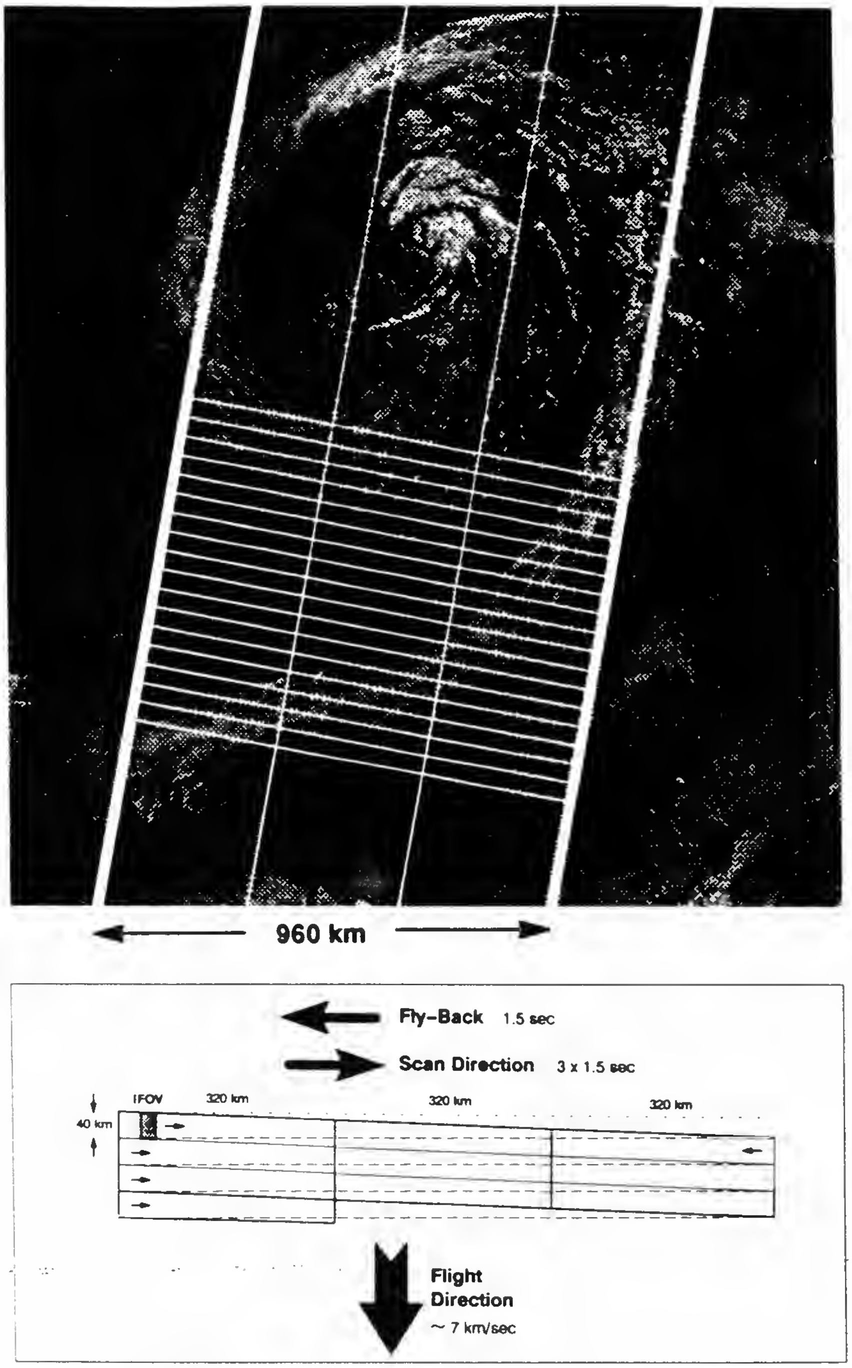

Figure 6. GOME scan pattern (graphic courtesy of DLR, Oberpfaffenhofen)

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Band	Wavelength range (nm)	Grating (l/mm)	Pixel resolution (nm)	Spectral resolution (nm)
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In the spectrometer optics, shown schematically in Figure 7, the light reflected off the scanning mirror is focussed by an anamorphic telescope such that the shape of the focus matches the entrance slit of the spectrometer (dimensions 10 mm x 100 µm. After the slit, the light is collimated by an off-axis parabolic mirror. It then strikes the quartz pre-disperser prism, causing a moderately wavelength dispersed beam. Another prism acts as channel separator: the upper edge of this prism reaches into the wavelength-dispersed beam, letting the longer wavelengths pass, reflecting the wavelength range 290–405 nm into Channel 2 by means of a dielectric reflecting coating, and guiding the wavelength range 240–295 nm internal to the prism into Channel 1. The unaffected wavelength range of 405–790 nm is then split up by a dichroic beam splitter into Channels 3 (400–605 nm) and 4 (590–790 nm).

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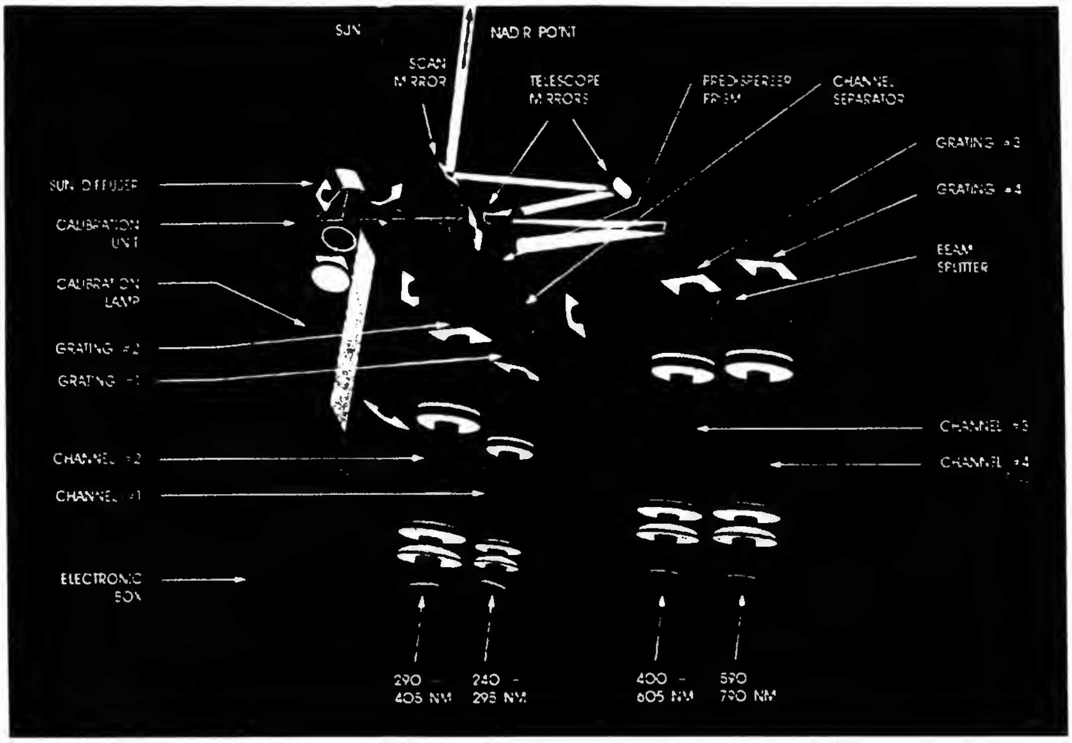

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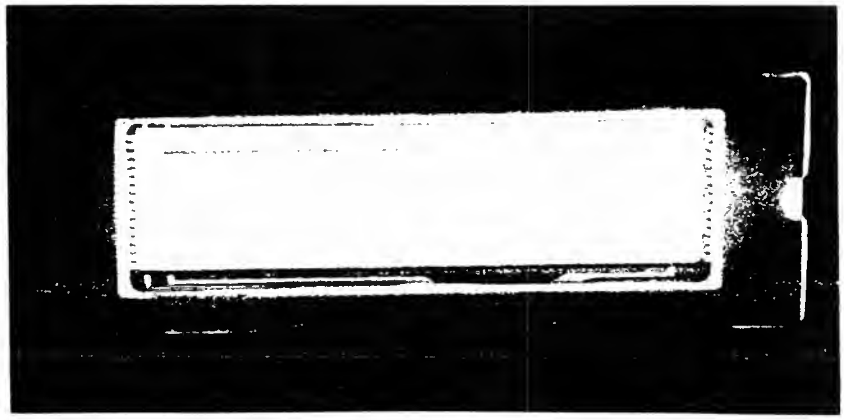
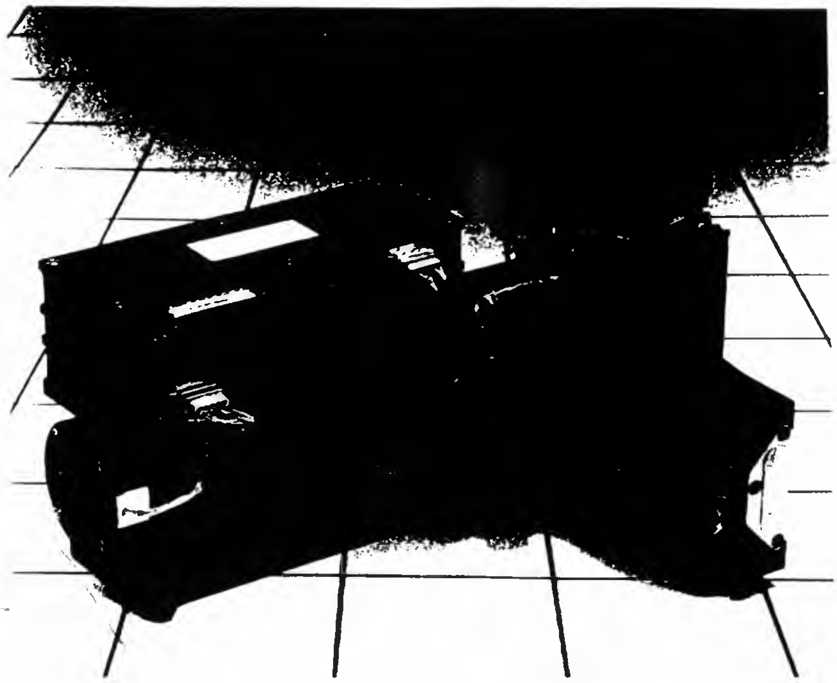
Previous NASA experience has shown that the diffuser is subject to degradation during its periods of exposure. Precautions are therefore taken by having:

Figure 8. Reticon RL1024SR detector chip





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The scanning unit consists of two separate assemblies, the Scan Mechanism (SM) and the Scan Unit Electronics Assembly (SUEA). The scan mechanism is located on the optical bench, with its rotation axis aligned with the satellite's flight direction. The axis carries a glued-on aluminium-coated mirror, which can be heated from the rear to drive off possible contaminants, if necessary.

A brushless DC motor actuates the scanner, the position of which is sensed by a resolver. The rotating part of the resolver, the mirror heater and the temperature sensor are connected to the static part via a flexible printed-circuit connection. The angular range of the scanner is limited to −63.8 to +192.2° with respect to nadir (0°) by software and end stops.

The rotation axis is supported by two spring-preloaded angular contact bearings, the balls of which are ion-plated with lead and the races are made of lead bronze. All structural parts (housing, pivot, etc.) are made from titanium.

Polarisation measurement device

The incoming light from the Earth's atmosphere can be partially polarised. Because the instrument's responses to the two orthogonal linear polarisation directions are not equal, there is a need to monitor the polarisation of the incoming light.

In the pre-disperser prism, light is internally reflected at the Brewster angle. About 5 % of this light, polarised normal to the plane of incidence, leaks away at this surface. This light is collected by an off-axis parabola, reflected by a mirror out of the plane of the optical bench, and then sensed by a custom-made photodiode array.

Because the device is not temperature-controlled, it is subject to drifts. To keep the impact of changing temperatures to a minimum, a second array of photodiodes with the same geometry, but not exposed to light, will be used to compensate for the dark current and its variability with temperature.

The measured signals are acquired by the DDHU, converted to digital signals, and included into the telemetry data (3 x 16 bit, 10.67 Hz).

Digital Data-Handling Electronics (DDHU)

The prime interface to the satellite's electrical subsystems is via the Digital Electronics Unit (DEU) of the Along-Track Scanning Radiometer (ATSR). Because the DEU now not only controls the ATSR's Infrared Radiometer (IRR) and Microwave Radiometer (MWR), but also GOME, a redundant DEU has been added, together with a DEU Switching Unit (DSU).

The DEU assumes all the normal functions of an Instrument Control Unit (ICU). Commands dedicated to GOME are expanded into a serial digital bit stream, initiating the appropriate actions within the DDHU. In the opposite direction, both housekeeping and scientific data are written by the DDHU into data buffers, from which they are requested by the DEU to be put into predefined fields of the ATSR S-band and X-band data streams.

Thermal-control hardware

The most critical aspect of the thermal control is the detector temperature, which is provided by the Peltier elements in each of the Focal-Plane Assemblies. The hot sides of the Peltiers are all connected, via copper bars and flexible connections, to a parallel pair of bent heat pipes, which end in the primary radiator exposed to deep space.

The DDHU and the scanning mirror electronics assembly have their own radiative surfaces for thermal control. The remainder of the instrument is wrapped in multi-layer insulation blankets. For cold non-operational phases, thermostat-controlled heater mats and resistors are directly powered from the payload's Power Distribution Unit.

Structure

All elements of the optics, mechanisms, electronics and thermal hardware are mounted on the optical bench, which is a nearly rectangular aluminium plate with stiffening ribs beneath. This optical bench is carried on four feet, one of which is round in cross-section and rather stiff. The other three are blade-shaped feet, with their flexing direction lying in the direction of the fixed foot. This prevents mechanical distortion of the optical alignment due to thermal expansion of the bench.

Beneath the optical bench, in the space between the ribs, the harness and the pipework for FPA evacuation are routed. An EMC shield protects the instrument from electromagnetic interference from the satellite's radars and communications system.

Operations

The GOME instrument has numerous measurement, calibration, and support modes. In particular, due to the varying light levels that will be experienced during each orbit, integration time settings will have to be adjusted frequently. In addition, once per day a Sun calibration has to be performed.

In order to limit the command traffic on the uplink, the DEU stores three different timelines, each of which can be activated automatically up to 16 times in sequence. One of these timelines is for normal operations, one for an orbit in which a Sun calibration is being performed, and one with a sidewards swath to cover the polar area (with the normal nadir-centred swath there would be a gap in coverage of about 4° around both poles).

About once per month, a wavelength mapping as function of the thermal variations will be performed with the wavelength calibration lamp. On these occasions a diffuser characterisation can also be carried out.

Lunar observations, which are restricted by the Sun–Moon–satellite scanner field-of-view geometry, will be performed whenever possible.

Data processing

GOME data will arrive together with the other 'low-bit-rate' data at the various ground stations to which the ERS tape recorders are downlinked. Extracted GOME data, together with orbit and attitude information, will then be shipped on Exabyte cassettes to the German Processing and Archiving Facility (D-PAF) in Oberpfaffenhofen. In a first processing step, the raw data will be corrected for instrument-induced errors and drifts, and provided with information on geo-location, Sun aspect angle, etc.

From these radiometrically and wavelength corrected geo-located spectra, the ozone total column amount, ozone vertical concentration profile, and data on aerosol loading and cloud cover can be retrieved. This will be done at distributed centres, according to the particular scientific expertise available. Time and budgets permitting, other atmospheric-constituent retrieval can be added to the range of data products generated. Finally, time and spatial averaging for long-term global-trend analyses is likely to be conducted (not yet specifically defined).

In addition to this off-line processing chain, some limited processing capabilities will also be installed at ESTEC, in order to evaluate the instrument performance after launch, optimise parameter settings and operating schemes, and to support possible scientific campaigns.

GOME should produce unique data as there will be no other instrument available on its time scale which duplicates its capabilities. The instrument fills a critical slot as far as future observing strategies are concerned, and GOME could well become the prototype for subsequent ozone-monitoring instruments. Its medium spectral resolution combined with a wide spectral range and absolute calibration is particularly important as it means that, in addition to applying the traditional backscatter approach, one can also use differential optical absorption spectroscopy to retrieve data with GOME.

Acknowledgements

We gratefully acknowledge the unfailing support of the GOME Science Team, headed by Prof. Dr. J. Burrows from the University of Bremen (D). Much of the work reported here has been done by the GOME Industrial Team, comprised of Officine Galileo (I), Laben (I), TPD/TNO (NL), Dornier (D) and the Rutherford Appleton Laboratory (UK), and BAe (UK) for the DEU modifications.

GOME: A New Instrument for ERS-2

A. Hahne, A. Lefebvre, J. Callies & R. Zobl
ERS Project Division, ESA Directorate for Observation of the Earth and Its Environment, ESTEC, Noordwijk, The Netherlands

The Global Ozone Monitoring Experiment, or GOME, is a new instrument that will be added to the original ERS-1 payload complement for the launch of the second European Remote-Sensing Satellite (ERS-2) in 1994. GOME is a nadir-viewing spectrometer which will observe solar radiation transmitted through or scattered from the Earth's atmosphere or from its surface. The recorded spectra will be used to derive a detailed picture of the atmosphere's content of ozone, nitrogen dioxide, water vapour, oxygen/oxygen dimer and bromine oxide and other trace gases. ERS-2's orbit will provide global Earth coverage every three days.

Introduction

In 1989, ESA decided to continue the ERS Programme beyond the expected lifetime of the ERS-1 satellite by approving the building and launch of the ERS-2 satellite. To provide the necessary continuity to the observations started by the instruments of ERS-1, ERS-2 is essentially a carbon-copy of the ERS-1 satellite. It was recognised, however, that there is an urgent need to investigate the composition and dynamic behaviour of the Earth's atmosphere. The ERS-2 Programme approval therefore included an experimental sensor for atmospheric research, the 'Global Ozone Monitoring Experiment' (GOME), which is essentially a scaled-down version of the SCIAMACHY instrument proposed for the European Polar Platform to be launched at the end of the century.

The inclusion of the GOME sensor in ERS-2 Programme was endorsed on the explicit understanding that:
- the sensor would be developed, tested, calibrated and integrated in the same time frame as the satellite and the other instruments would be rebuilt
- the resource demands of the sensor would have to be satisfied from the existing system margins, imposing stringent limitations on mass, power and data rate
- no major upgrades in the ERS Ground Segment would be needed, and the financial burden for the data-processing algorithms and software would be borne by scientific institutions and/or national agencies.

The limitations on resources have already led to drastic changes in the instrument concept, because at the Baseline Design Review held in February 1991 it became obvious that the power/energy demand exceeded the available margin. Instead of GOME having its own interface to the On-Board Computer (OBC) and to the Instrument Data Handling and Transmission (IDHT) system, it was decided to provide these functions via the existing interfaces of the Along-Track Scanning Radiometer (ATSR) instrument.

Scientific objectives

Ozone (O_3) is a tri-atomic form of oxygen, formed by hard ultraviolet radiation in the atmospheric layer between about 15 and 45 km altitude, the so-called 'stratosphere'. It absorbs radiation in the spectral region between 240 and 310 nm, preventing these harmful rays from reaching the ground in large quantities. This naturally protective atmospheric layer is now being threatened by human activities, in particular by the steady release of chlorfluorocarbons (CFCs) into the atmosphere. The accumulated anthropogenic effects on stratospheric ozone are believed to be causing a steady depletion of the ozone layer by approximately 0.3 % per year.

The chemistry of the stratosphere is very complex. The hard ultraviolet radiation causes the breakup of many of the available species into reactive fragments, which lead to a multitude of possible reactions. Normally, the rates of these reactions depend not only on the nature of the species, but also on local pressure, temperature, radiative fluxes in the different wavelength regions, vertical and horizontal transport processes, etc. Thus, in order to understand the ozone chemistry fully, it is not sufficient just to measure the ozone; one must also monitor the abundances of many other species, including very

reactive intermediate species occurring in only very low concentrations.

Reflecting this need, GOME is intended to measure other species as well as to observe aerosols and polar stratospheric clouds which play significant roles in the heterogeneous processes associated with ozone chemistry. It is hoped that some of these species may be observed in the troposphere, another part of the atmosphere believed to be affected by man's activities. However, the presence of clouds may make this difficult.

For this GOME will exploit spectroscopy, which is a viable technique for observing trace species in the atmosphere. Sunlight, reflected by the ground surface and scattered within the different atmospheric layers, carries the absorption signatures of the absorbing species (Figs. 1 & 2). The GOME instrument is designed to collect this light over the entire wavelength region from 240 to 790 nm, in which not only ozone, but also a number of other atmospheric species absorb. In addition to the classical backscatter technique, the GOME instrument exploits the novel technique of 'Differential Absorption Spectroscopy' (DOAS)*.

Satellite mission and instrument accommodation

Like its predecessor ERS-1, ERS-2 will fly in a Sun-synchronous polar orbit with an inclination of 98°, with a mean altitude of 780 km and a local time of 10.30 h for the equator crossing on the descending node. This results in an orbital period of approximately 100 min and a ground speed for the subsatellite point of 7 km/s.

The GOME instrument's instantaneous field of view has been chosen to be 40 km x 2 km, or 2.8° x 0.14°. Via the

* Developed by U. Platt (Heidelberg, FRG)

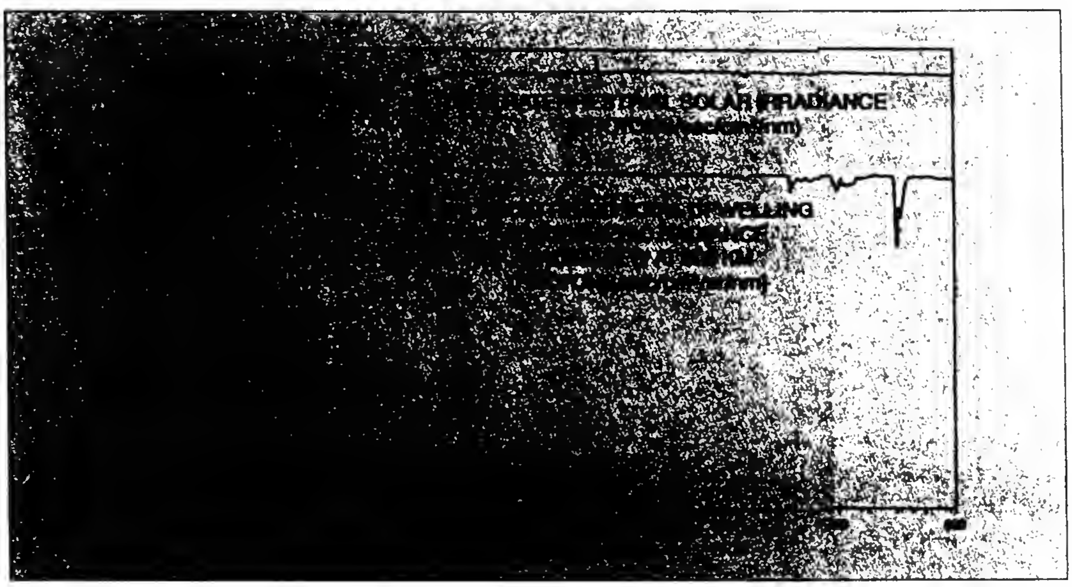


Figure 1. LOWTRAN simulation of spectral radiances at the top of the atmosphere in the wavelength range of the GOME instrument, i.e. 240–790 nm

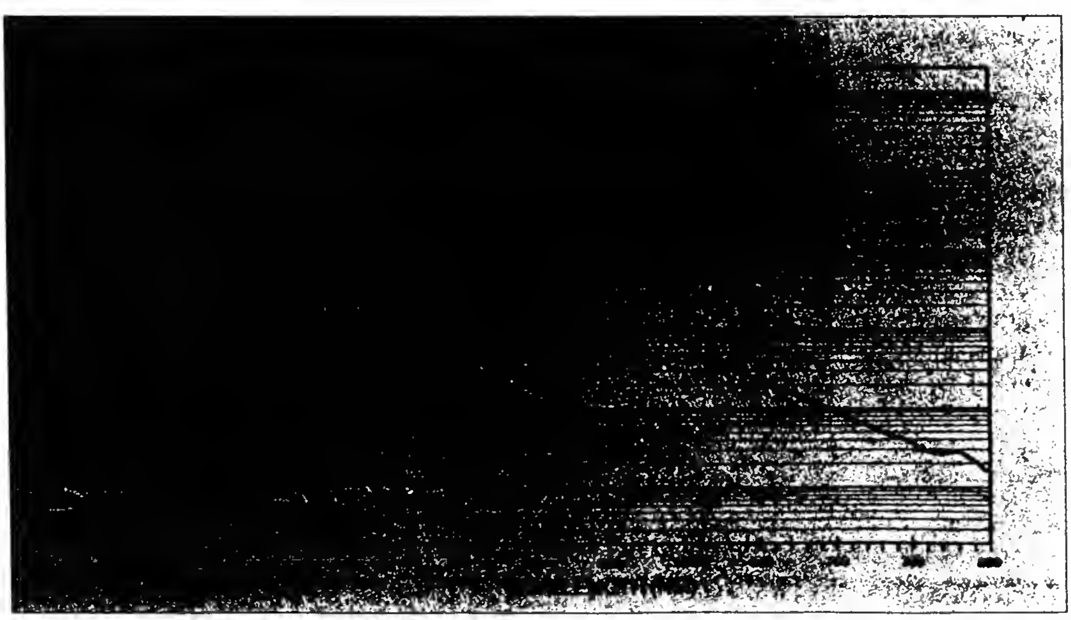


Figure 2. Ozone absorption cross-sections in the wavelength range of the GOME instrument

Figure 3. Artist's impression of the GOME instrument's scanning geometry

movement of the instrument's scanning mirror, this instantaneous field of view can be scanned across the satellite's track. With a ±31° scan, global coverage can be achieved within 3 days, except for a gap of approximately 4° around both poles. To overcome this limitation, a special pole-viewing mode has been included (Figs. 3 & 4a,b).

The GOME instrument is mounted externally, on the surface of the payload module facing in the flight direction (i.e. the −Y face), with a clear field of view in the nadir direction (Fig. 5). It is thermally decoupled from the spacecraft structure as far as possible.

Photon flux computations show that for the visible/near-infrared channels, a good signal-to-noise ratio can be achieved with a 1.5 s integration time on the detector. The time for one forward scan has therefore been set to 4.5 s. For the flyback of the scanning mirror, another 1.5 s have been allowed, resulting in the scan pattern shown in Figure 6, with a ground pixel size of 320 km x 40 km.

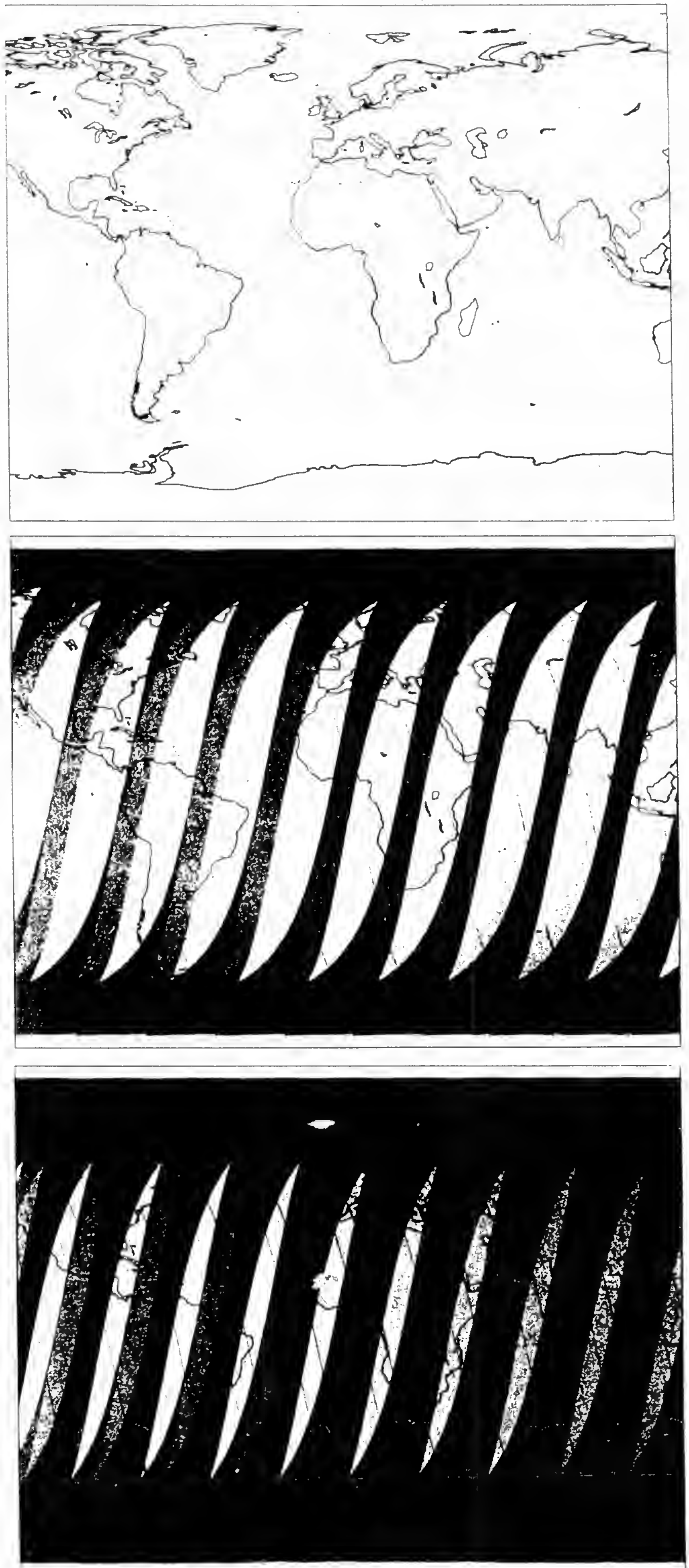
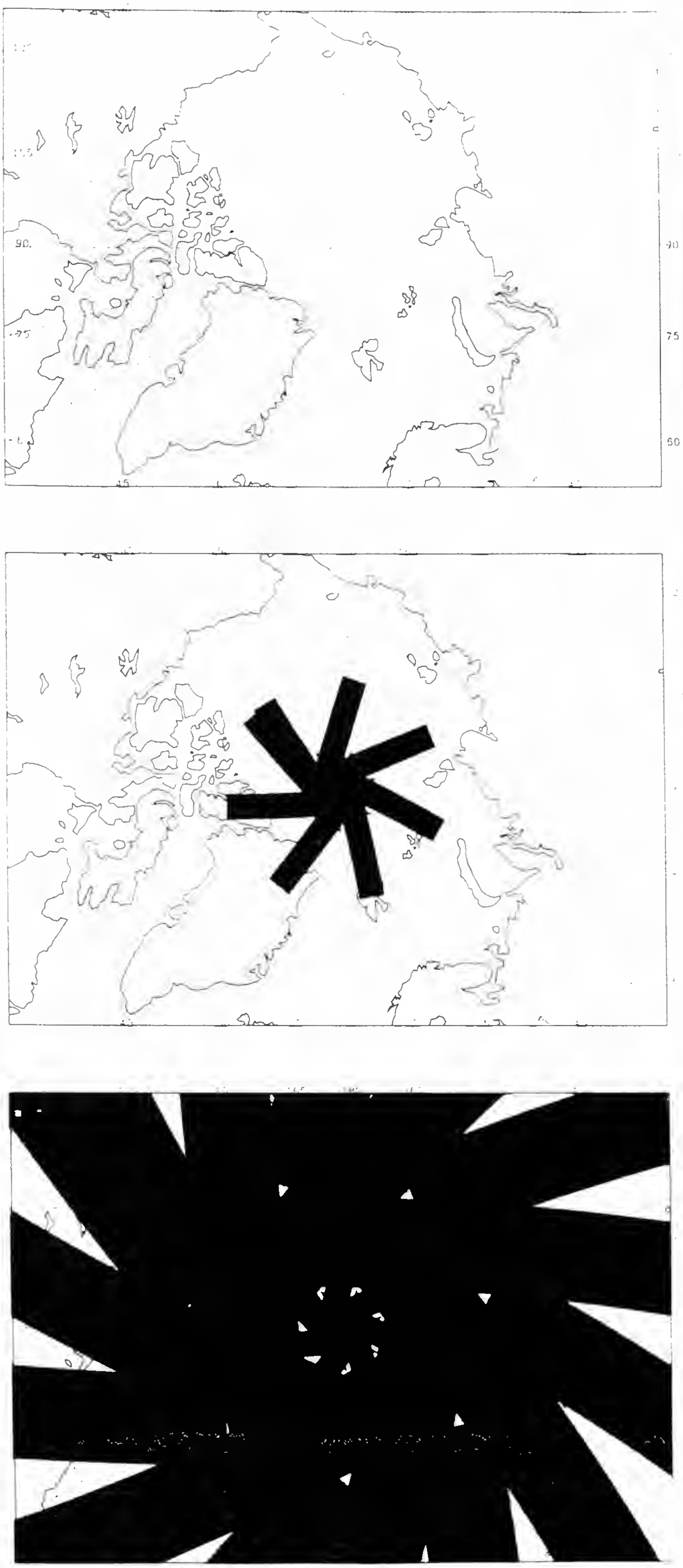
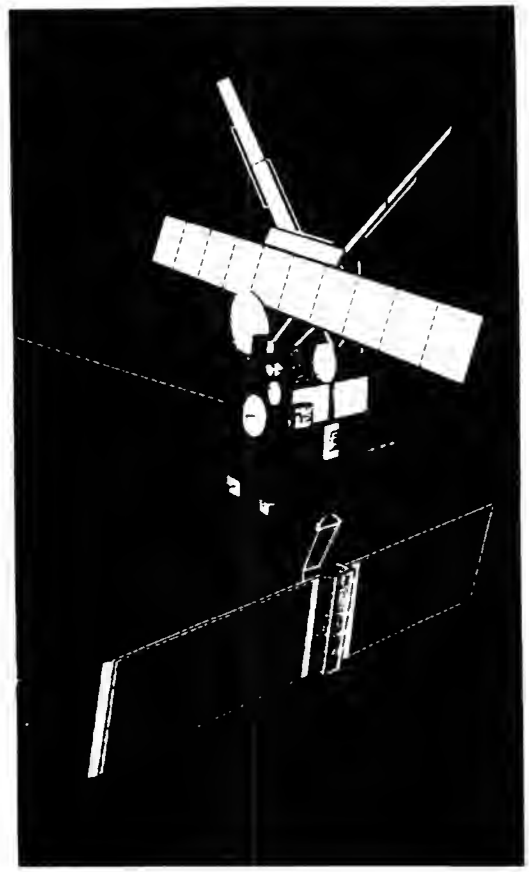


Figure 4a. Three-day coverage map for GOME





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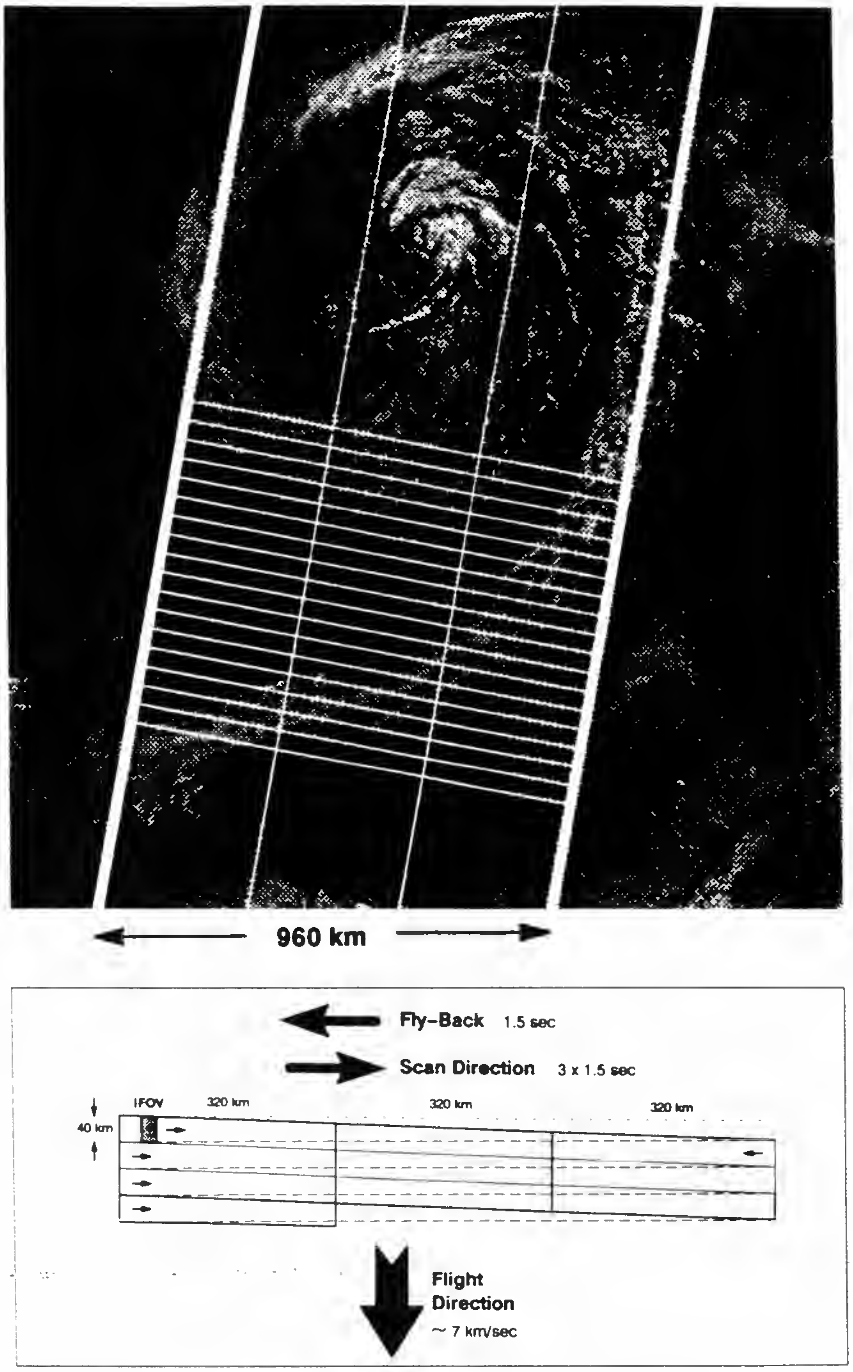

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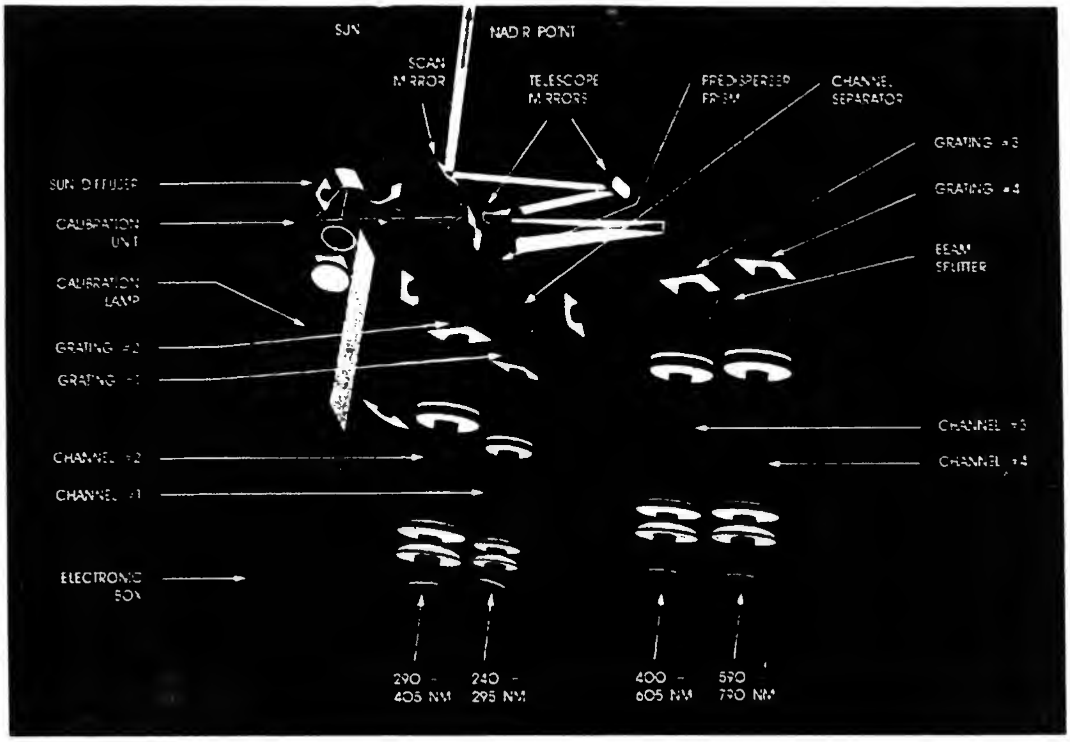

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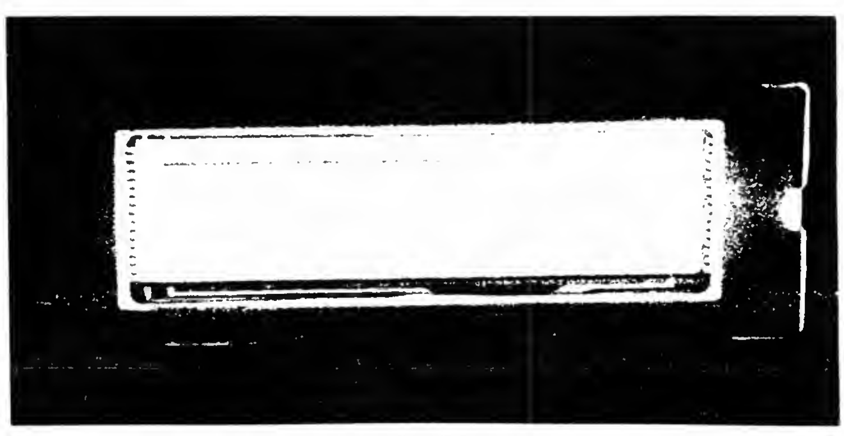

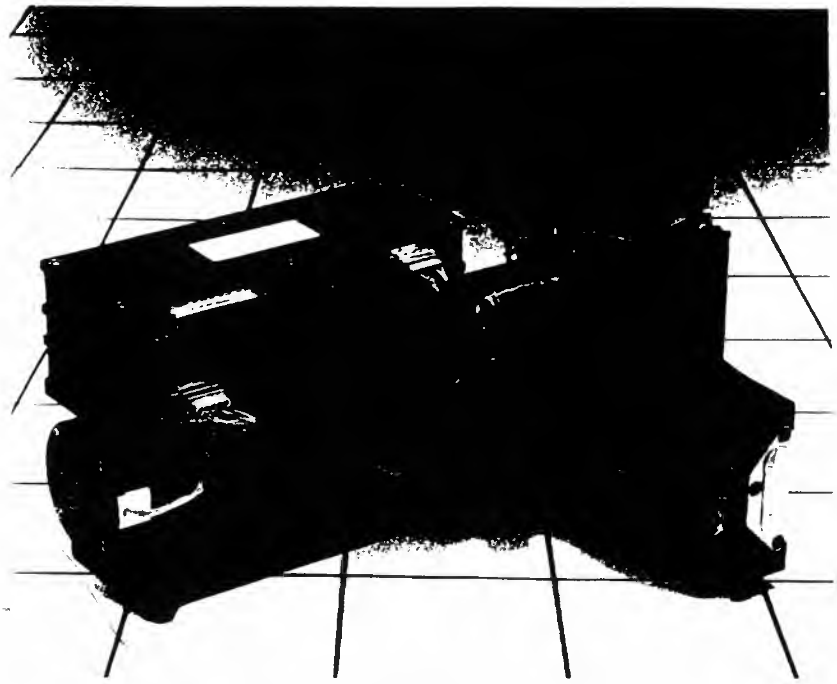

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In the pre-disperser prism, light is internally reflected at the Brewster angle. About 5 % of this light, polarised normal to the plane of incidence, leaks away at this surface. This light is collected by an off-axis parabola, reflected by a mirror out of the plane of the optical bench, and then sensed by a custom-made photodiode array.

Because the device is not temperature-controlled, it is subject to drifts. To keep the impact of changing temperatures to a minimum, a second array of photodiodes with the same geometry, but not exposed to light, will be used to compensate for the dark current and its variability with temperature.

The measured signals are acquired by the DDHU, converted to digital signals, and included into the telemetry data (3 x 16 bit, 10.67 Hz).

Digital Data-Handling Electronics (DDHU)

The prime interface to the satellite's electrical subsystems is via the Digital Electronics Unit (DEU) of the Along-Track Scanning Radiometer (ATSR). Because the DEU now not only controls the ATSR's Infrared Radiometer (IRR) and Microwave Radiometer (MWR), but also GOME, a redundant DEU has been added, together with a DEU Switching Unit (DSU).

The DEU assumes all the normal functions of an Instrument Control Unit (ICU). Commands dedicated to GOME are expanded into a serial digital bit stream, initiating the appropriate actions within the DDHU. In the opposite direction, both housekeeping and scientific data are written by the DDHU into data buffers, from which they are requested by the DEU to be put into predefined fields of the ATSR S-band and X-band data streams.

Thermal-control hardware

The most critical aspect of the thermal control is the detector temperature, which is provided by the Peltier elements in each of the Focal-Plane Assemblies. The hot sides of the Peltiers are all connected, via copper bars and flexible connections, to a parallel pair of bent heat pipes, which end in the primary radiator exposed to deep space.

The DDHU and the scanning mirror electronics assembly have their own radiative surfaces for thermal control. The remainder of the instrument is wrapped in multi-layer insulation blankets. For cold non-operational phases, thermostat-controlled heater mats and resistors are directly powered from the payload's Power Distribution Unit.

Structure

All elements of the optics, mechanisms, electronics and thermal hardware are mounted on the optical bench, which is a nearly rectangular aluminium plate with stiffening ribs beneath. This optical bench is carried on four feet, one of which is round in cross-section and rather stiff. The other three are blade-shaped feet, with their flexing direction lying in the direction of the fixed foot. This prevents mechanical distortion of the optical alignment due to thermal expansion of the bench.

Beneath the optical bench, in the space between the ribs, the harness and the pipework for FPA evacuation are routed. An EMC shield protects the instrument from electromagnetic interference from the satellite's radars and communications system.

Operations

The GOME instrument has numerous measurement, calibration, and support modes. In particular, due to the varying light levels that will be experienced during each orbit, integration time settings will have to be adjusted frequently. In addition, once per day a Sun calibration has to be performed.

In order to limit the command traffic on the uplink, the DEU stores three different timelines, each of which can be activated automatically up to 16 times in sequence. One of these timelines is for normal operations, one for an orbit in which a Sun calibration is being performed, and one with a sidewards swath to cover the polar area (with the normal nadir-centred swath there would be a gap in coverage of about 4° around both poles).

About once per month, a wavelength mapping as function of the thermal variations will be performed with the wavelength calibration lamp. On these occasions a diffuser characterisation can also be carried out.

Lunar observations, which are restricted by the Sun–Moon–satellite scanner field-of-view geometry, will be performed whenever possible.

Data processing

GOME data will arrive together with the other 'low-bit-rate' data at the various ground stations to which the ERS tape recorders are downlinked. Extracted GOME data, together with orbit and attitude information, will then be shipped on Exabyte cassettes to the German Processing and Archiving Facility (D-PAF) in Oberpfaffenhofen. In a first processing step, the raw data will be corrected for instrument-induced errors and drifts, and provided with information on geo-location, Sun aspect angle, etc.

From these radiometrically and wavelength corrected geo-located spectra, the ozone total column amount, ozone vertical concentration profile, and data on aerosol loading and cloud cover can be retrieved. This will be done at distributed centres, according to the particular scientific expertise available. Time and budgets permitting, other atmospheric-constituent retrieval can be added to the range of data products generated. Finally, time and spatial averaging for long-term global-trend analyses is likely to be conducted (not yet specifically defined).

In addition to this off-line processing chain, some limited processing capabilities will also be installed at ESTEC, in order to evaluate the instrument performance after launch, optimise parameter settings and operating schemes, and to support possible scientific campaigns.

GOME should produce unique data as there will be no other instrument available on its time scale which duplicates its capabilities. The instrument fills a critical slot as far as future observing strategies are concerned, and GOME could well become the prototype for subsequent ozone-monitoring instruments. Its medium spectral resolution combined with a wide spectral range and absolute calibration is particularly important as it means that, in addition to applying the traditional backscatter approach, one can also use differential optical absorption spectroscopy to retrieve data with GOME.

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