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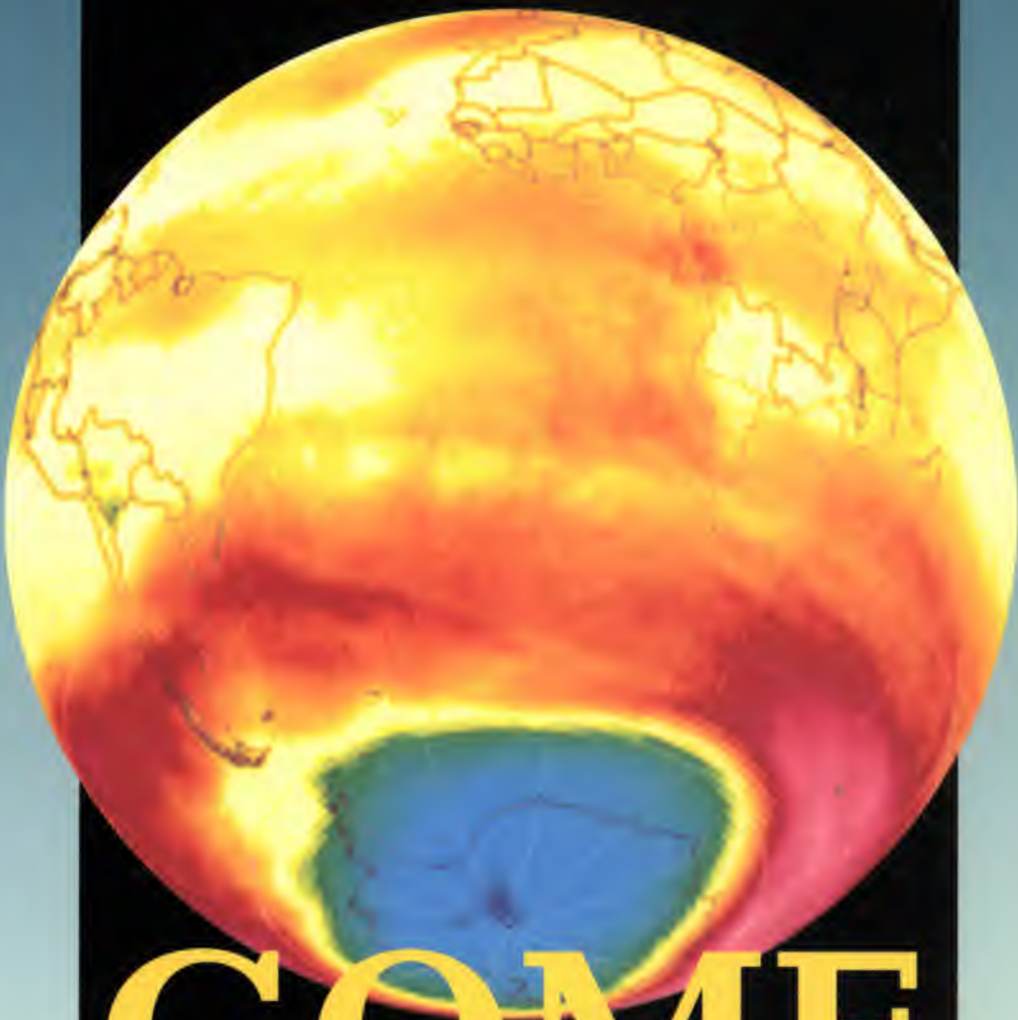

GOME

Global Ozone Monitoring Experiment

USERS MANUAL

SP-1182
September 1995

GLOBAL OZONE MONITORING EXPERIMENT

GOME

USERS MANUAL

european space agency / agence spatiale européenne

COVER

Image showing degradation of upper atmospheric ozone (the "ozone hole") over the South Pole as taken by the NASA Total Ozone Mapping System (TOMS). Satellite composite image courtesy of NASA (National Aeronautics and Space Administration- U.S.A.).

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"Better" is the enemy of "good enough"

D. Heath

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1. Introduction

1.1 Scope

This users manual has been drawn up with the purpose of giving the (actual or potential) user of GOME data a reference at hand which describes, concisely yet comprehensively, the GOME instrument, its features and limitations, and the satellite and supporting ground system.

Following a brief description of the instrument's history, both programmatically and technical (in terms of development programme), the essential features of the ERS-2 satellite and mission are described in Chapter 2, as far as they are of relevance to GOME. Chapter 3 summarises the main requirements for the instrument, while Chapter 4 describes in detail the technical implementation. In Chapter 5, the results of the functional and performance tests are reported; in Chapter 6, the results of the instrument calibration are noted.

The formats and possibilities for commanding the instrument, both by direct command and by timeline, are described in Chapter 7. Additionally, the contents of the S-band ('housekeeping') and X-band ('science data') telemetry are provided.

The operational schemes for operating the GOME are reported in Chapter 8. After a general description of how ERS-2 is commanded and controlled, the GOME operations as conceived prior to launch are outlined. Plans for the commissioning phase for the first six months after launch are reported in a special section.

Chapter 9 deals with the transmission of the data to ground, their forwarding to the processing centre, and what processing steps are envisaged to arrive at the final data products. Chapter 10 concludes with the plan for the validation of data, and gives a brief look into the future. Various industrial, institutional, and scientific contributors to the GOME Project are also acknowledged.

This manual does **not** address any underlying scientific issues; these are described in great detail in "The GOME Interim Science Report" /6/ and are not repeated here.

1.2 Historic Evolution of the GOME Programme

In 1988, the executive of the European Space Agency started with the preparatory work for ERS-2, the follow-on to ERS-1. At that time, the assembly phase of the ERS-1 programme was just starting. It was felt necessary to complement the capabilities of ERS-2 with instrumentation which could contribute information for the general discussions taking place in public about issues such as global warming and ozone depletion. On 29 November 1988, selected European scientists, involved in atmospheric chemistry instrumentation, were requested to submit proposals for such an instrument for inclusion into the ERS-2 payload, possibly replacing the Infrared Radiometer part of the ATSR instrument.

Among the proposals received was one prepared jointly by J. Burrows and P. Crutzen named "SCIAMINI", because it was derived from the "SCIAMACHY" instrument concept proposed for flight on the Polar Platform (which later became part of the ENVISAT Project). As an independent ESA in-house assessment of the involved technology confirmed, in principle, the feasibility of such a concept, the executive was given authority to proceed with a more detailed instrument concept study. (Although

right from the beginning there were some drastic simplifications: no limb view, only one unit rather than two next to each other, etc.)
By the end of 1989, a contract was placed with the Dutch optical firm TPD to elaborate on the optical concept in greater detail. In parallel, ESA performed in-house studies on the possible accommodation of the instrument inside the ERS-2 Service Module. In February 1990, initial contacts were made with the Italian firms Officine Galileo and Laben, in order to complement TPD in a Phase B study, scheduled to begin in July 1990. In parallel, the Earth Observation Programme Board endorsed the ERS-2 Programme, including GOME, the programmatic and technical feasibility of which had been reported in a special paper /1/.

The industrial Phase B activities culminated in a Design Baseline Review which was held 12 and 13 March 1991 in the Hotel Noordzee, Noordwijk, The Netherlands. The outcome was quite significant in a number of areas:

- The electrical configuration presented, with its own Instrument Control Unit (ICU) and a premultiplexer to multiplex GOME and ATSR (which was finally retained) data prior to presenting the combined stream to the Instrument Data Handling and Transmission Subsystem (IDHT), was considered to consume far too much power. At that time, ERS-1 had not been launched and the actual system margins were not yet established. Instead, it was proposed to provide these services through the Digital Electronics unit of the ATSR.

- Change to active thermal control of the detectors by Peltier coolers rather than passive radiators.
- Change in calibration optics: light path via the scan mirror, protection of the sun diffuser by a shutter and mesh, possibility to monitor diffuser degradation by the calibration lamp.

On this basis, the phase C/D contractual documentation was prepared and negotiated, resulting in a kick-off meeting on 28 April 1992. A separate contract was placed with RAL and BAe for modifications to the ATSR DEU hardware and software.

The political and technical boundary conditions for the inclusion of GOME into the ERS-2 programme can be summarised as follows:

- GOME must not jeopardise any other aspect of the ERS-2 mission, either technically or programmatically;

- GOME must be constrained within the system margins as known by the time of its approval: 30 kg, 60 x 30 x 20 cm, 40 kbps, ~30 W, non-redundant;

- No financial provisions could be made in the ERS-2 Programme for GOME data routing and processing;

- Project Management and system engineering must be done directly by ESTEC staff: this was considered the only possibility to comply with the schedule constraints.

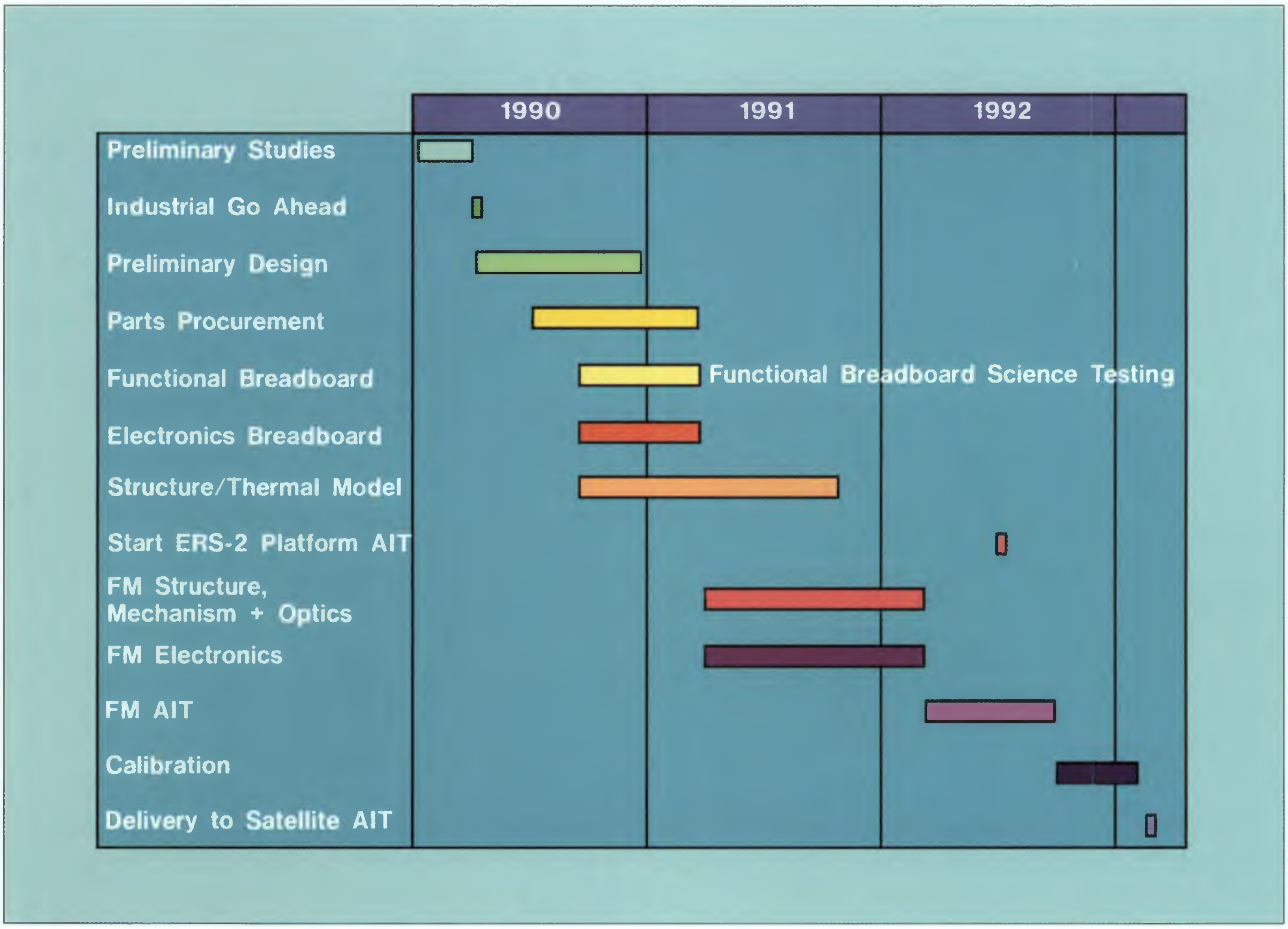


Figure 1.3-1 GOME Master Schedule, as of May 1990 (reference 1)

1.3 The Instrument Development Programme

The initial programme for the GOME instrument development as politically envisaged /1/ implied some breadboarding activities of critical subunits and a benchtop model for scientific testing, but it was essentially a protoflight programme aimed for a delivery in early 1993 (Fig. 1.3-1).

Soon after the detailed definition started of what should comprise the breadboard model (BBM), it became obvious that some critical performance parameters could be evaluated only in vacuum. So the first upgrade to the BBM concerned its suitability for thermal vacuum testing. In the next step, it was then realised that the critical aspect of spectral stability, in particular, could only be thoroughly evaluated if the structure would be fairly close to the final one. After all these definitions had been implemented, the final step to a full engineering model was to subject the instrument model to a full environmental test programme at qualification levels: vibration, EMC, and thermal vacuum. In addition, the model was then used for interface testing with the ATSR-DEU and with the entire payload in the payload TB/TV test, and was also subjected to a full calibration programme to exercise all necessary set-ups and procedures.

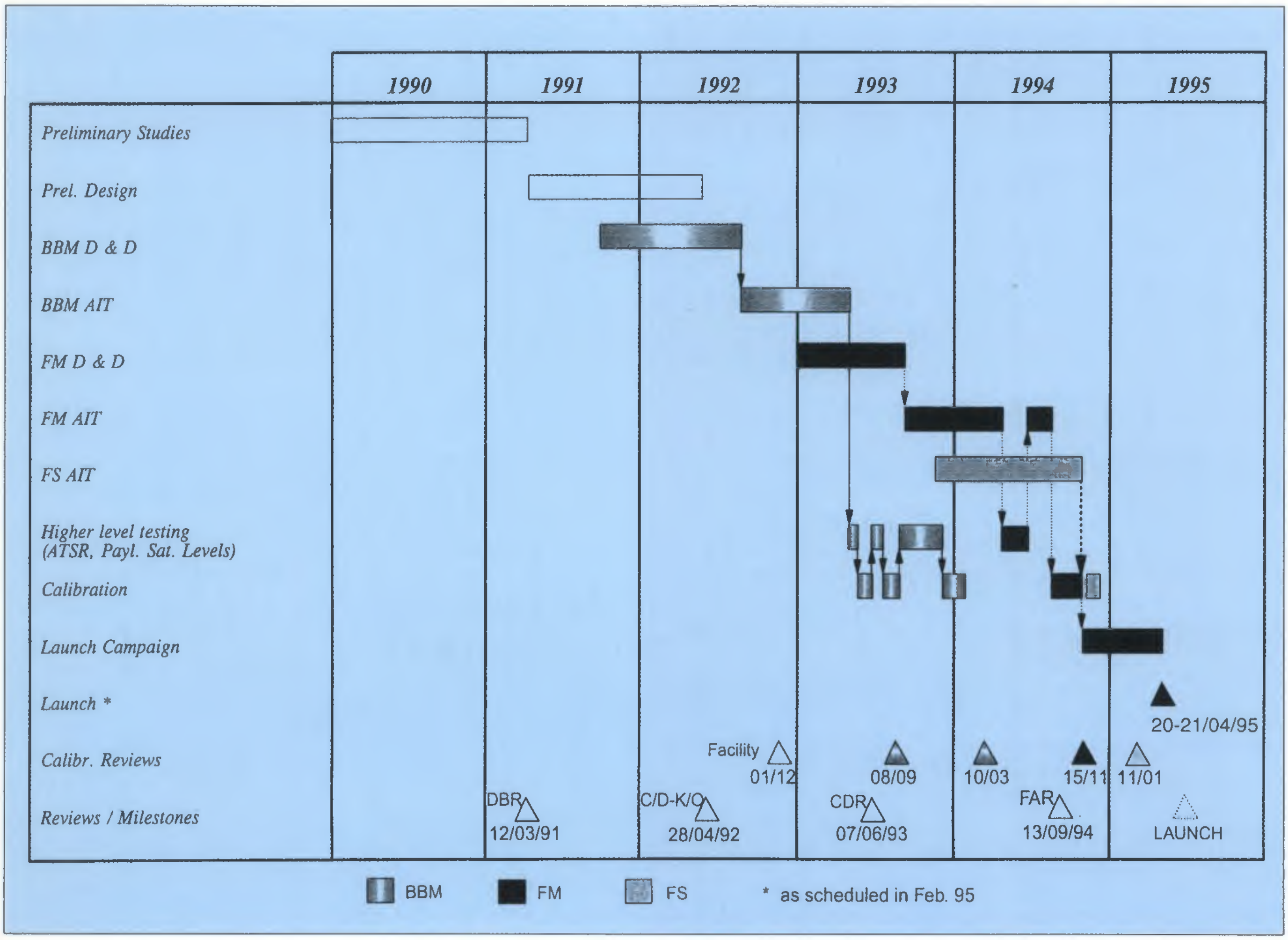


Figure 1.3-2 GOME Development Programme "as run"

While this was still under way, the Flight Model (FM) programme started. For schedule reasons, after the instrument level vibration and EMC tests, the FM was delivered for participation in satellite-level alignment, vibration, acoustic and EMC tests and was then returned to the contractor for TV test. The subsequent calibration programme benefitted greatly from the dry run executed on the BBM; the finalised FM was delivered just in time to go on the same transport to the launch site as the satellite. Finally, a Flight Spare model (FS) was produced, which went through the normal sequence of vibration/EMC/TV testing, followed by the same calibration programme as for the FM.

A summary of the "as run" development programme is given in Figure 1.3-2.

It is the intention to use the BBM and the FS, once no longer needed after the launch of the FM, for scientific activities such as ground validation, acquisition of reference spectra, or cross-calibration with other instruments.

2. The ERS-2 Satellite and Mission

2.1 The ERS-2 Satellite and Payload

Basically, the ERS-2 Satellite consists of two distinct modules: the Payload Module, carrying (nearly) all the instruments, and the Satellite Module, providing all the necessary services such as power generation and distribution, attitude control, telemetry link, onboard computer, etc.

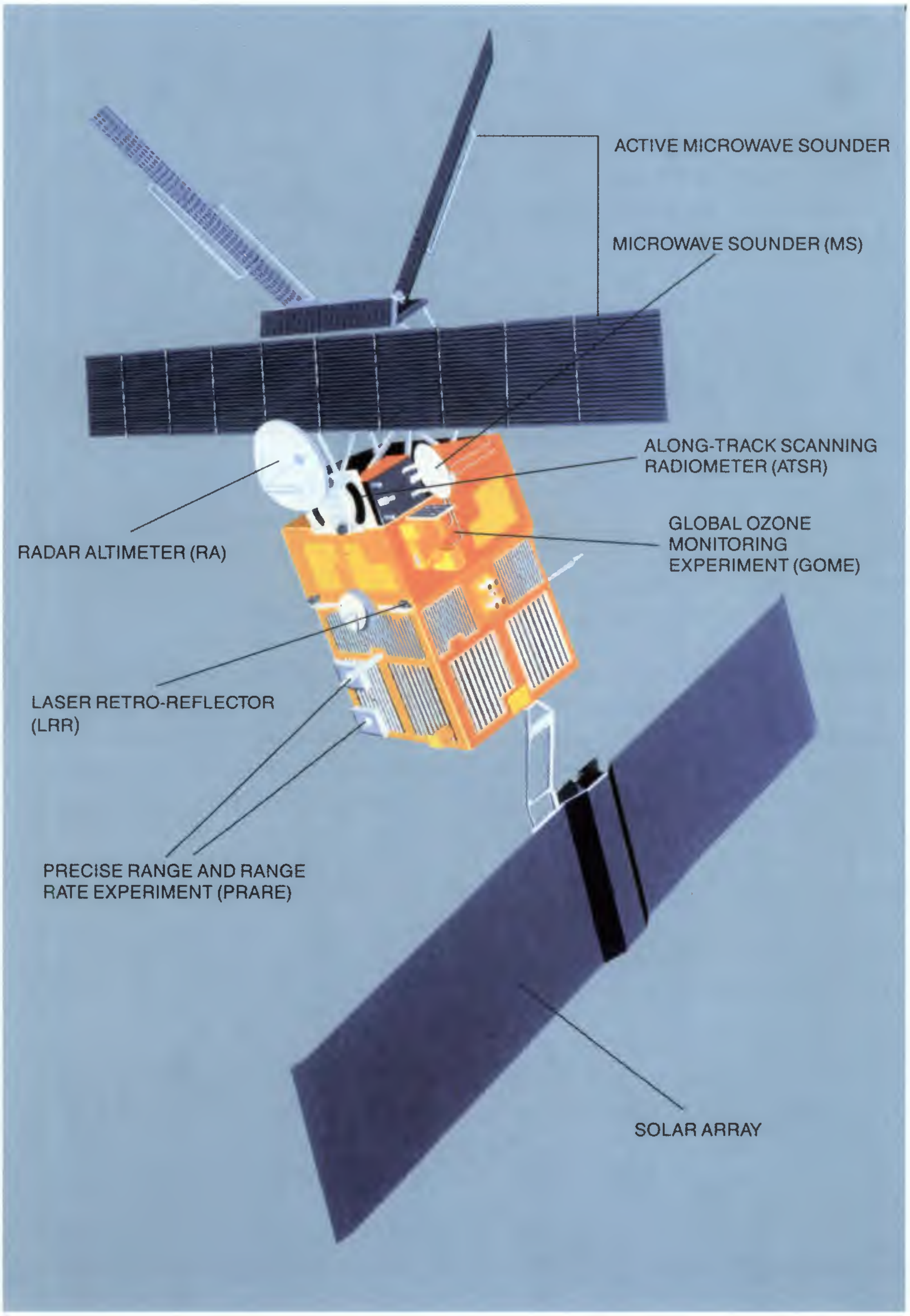


Figure 2.1-1 Overall ERS-2 Satellite

The payload consists of:

- **a. Active Microwave Instrument (AMI)**
  The AMI is comprised of two separate radars - a Synthetic Aperture Radar (SAR) and a Wind Scatterometer. These enable three modes of operation - Image Mode, Wave Mode (both performed by the SAR) and Wind Mode (performed by the Wind Scatterometer).
- **b. Radar Altimeter (RA)**
- **c. Along-Track Scanning Radiometer (ATSR)**
- **d. Precise Range and Range-Rate Equipment (PRARE)**
- **e. Laser Retroreflector**
- **f. GOME**

a. Active Microwave Instrument (AMI)

In Image Mode, the SAR obtains strips of high-resolution imagery, 100 km in width, to the right of the satellite flight path. The 10 m long antenna, aligned parallel to the flight track, directs a narrow radar beam onto the Earth's surface across the swath. Imagery is built up from the time delay and strength of the return signals, which depend primarily on the roughness and dielectric properties of the surface and its distance from the satellite. Operating in Image Mode excludes operating in the other AMI modes, and power considerations limit operating times to a maximum of 12 minutes per orbit. The data rate of 105 Mbps it too high to allow on-board storage, and so images are only acquired within the reception zones of suitably-equipped ground stations.

Wave Mode operation of the SAR measures the changes in radar reflectivity of the sea surface due to the surface waves, and provides 5 km x 5 km images ("imagettes") at intervals of 200 km along the track. These imagettes are transformed into spectra providing information about wave length and direction of wave systems. Series of power spectra can be used to determine the evolution of swell wave systems.

The **Wind Scatterometer** uses three sideways-looking antennae, one pointing normal to the satellite flight path, one pointing 45° forwards and the third pointing 45° backwards. These antenna beams continuously illuminate a swath 500 km wide as the satellite advances along its orbit, and each provides measurements of radar backscatter from the sea surface for overlapping 50 km resolution cells using a 25 km grid-spacing. This results in three independent backscatter measurements relating to cell centre nodes on a 25 km grid, which have been obtained using the three different viewing directions and are separated by only a very short time delay. Calculation of the surface wind vector in terms of speed and direction takes place using these so called "triplets" within a mathematical model, which defines the relationship between backscatter, wind speed, wind direction and incidence angle of the observation.

The Wind Scatterometer cannot be operated in parallel with the SAR in Image Mode; however, parallel operation of the wind and wave modes is possible (Wind/Wave Mode).

b. Radar Altimeter (RA)

The Radar Altimeter is a nadir-pointing pulse radar designed to measure the echoes from ocean and ice surfaces. It has two measurement modes, optimised for measurements over ocean and ice, respectively. In ocean mode, it is used to measure wave height, surface wind speed and sea-surface elevation, the last of which is appropriate to the study of ocean currents, the tides and the global geoid. In ice mode, the instrument, operating with a coarser resolution, provides information on ice sheet surface topography, ice types and sea/ice boundaries.

c. Along-Track Scanning Radiometer (ATSR)

The ATSR consists of two instruments, an Infrared Radiometer (IRR) and a Microwave Sounder (MWS). The **Infrared Radiometer** is a four-channel infrared radiometer providing measurements of sea surface and cloud-top temperatures, with higher accuracies than similar instruments flown on previous satellites. The scanning technique enables the Earth's surface to be viewed at two different angles (0° and 52°) in two curved swaths 500 km wide and separated along the flight track by about 700 km. Data from the two swaths are then combined to eliminate atmospheric influence in the calculation of sea-surface temperature. The instrument has been designed to provide an absolute accuracy in sea-surface temperature of better than O.5 K, when averaged over areas of 50 km x 50 km and in conditions of up to 80% cloud cover. For cloud-free pixels, of l km x l km, the relative accuracy is about 0.1 K.

The **Microwave Sounder** is a nadir-viewing passive radiometer providing measurements of the total water content of the atmosphere within a 20 km footprint. This is used to improve the accuracy of sea surface temperature measurements and also to provide accurate tropospheric range correction for the Radar Altimeter.

d. Precise Range and Range-Rate Equipment (PRARE)

The PRARE is an all-weather microwave ranging system which was designed to perform high-precision two-way microwave range and range-rate measurements using ground-based transponder stations. These measurements were supposed to be used for orbit determination and for geodetic applications. Unfortunately, the PRARE suffered fatal damage to the Random Access Memory due to radiation after a few hours of nominal operations. An improved version of PRARE is being built for ERS-2.

e. Laser Retroreflector

The Laser Retroreflector is a passive optical device which is used as a target by ground-based laser ranging stations and thus enables the accurate determination of the satellite's altitude.

f. Global Ozone Monitoring Experiment (GOME)

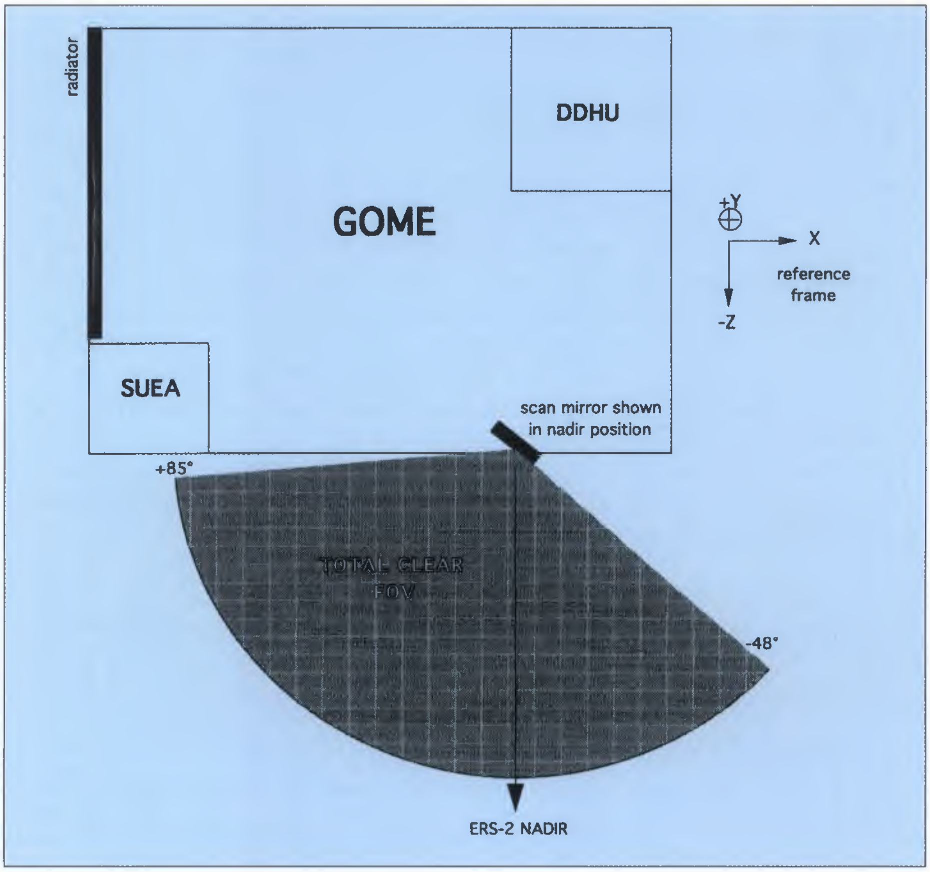
The Global Ozone Monitoring Experiment is the subject of this Guide.

2.2 GOME Accommodation

GOME is accommodated at the outside wall of the payload module, on the panel which is facing the flight direction (-y panel). It has a clear field of view to the Nadir direction and in the forward direction, such that it can perform across-track scans and sun calibrations when it is approximately over the North Pole.

At high elevation angles (+75 to +85° with respect to Nadir), GOME can also occasionally observe the moon. Figure 2.2-1 shows the field of view of the scan mirror (in the along-track direction, i.e. into and out of the plane of the paper, it is ±1.4° symmetrically to the paper's plane), whereas Figure 2.2-2 gives the geometry of the Sun calibration Field of View.

Figure 2.2-1 GOME Field of View of scan mirror about the Y-axis



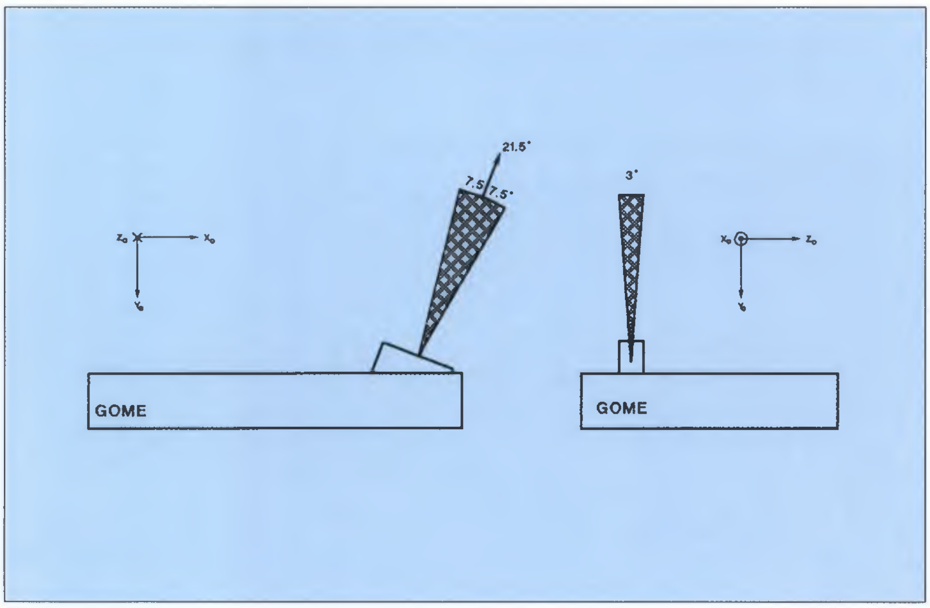


Figure 2.2-2 Geometry of sun calibration Field of View

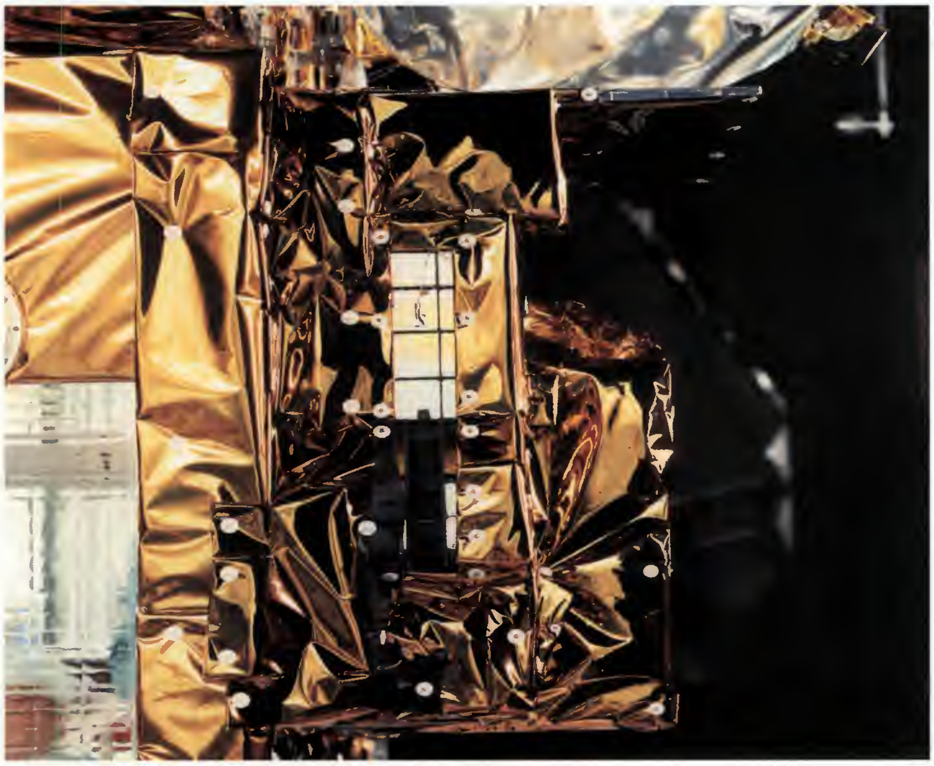


Figure 2.2-3 Integrated Instrument wrapped in MLI blankets.

The mechanical interface to the satellite is provided by four feet, each of which is attached by four screws, with thermal insulating washers, to the aluminium honeycomb panel. The somewhat asymmetrical mounting pattern is driven by the need to keep clear from existing inserts for carrying electronic equipment mounted at the inside of the payload module. The four feet carry the optical bench. The foot next to the GOME aperture has a circular cross section and provides a tight register for the optical bench. The other three feet have blade-shaped rectangular cross sections, with the bending direction in the connecting line to the fixed foot. In this way, differential thermal expansion between mounting panel and optical bench does not introduce stresses and thermal distortions into the optical path.

Next to the fixed foot, and immediately below the main aperture, is an optical reference cube to which the alignment of the optical path is done. This cube is also used to reference the GOME alignment to the satellite reference coordinate system. During flight, the alignment cube is covered by a small black cover. The actual values of alignment offset with respect to the satellite reference coordinate system were:

about x	:	0.042 deg.
about y	:	-0.004 deg.
about z	:	0.013 deg.

Except for the apertures, the external radiator, and the radiators of the electronic boxes, the entire instrument is wrapped with multi-layer insulation blankets. This, together with the insulation of the mounting feet, provides for optimum thermal decoupling from the environment. Figure 2.2-3 shows the instrument as integrated onto the payload module.

The instrument is electrically supplied by two cable looms coming from the inside of the satellite and running down from the connector bracket immediately underneath the antenna support structure. For further details, see Chapter 4.8.

2.3 The ERS-2 Mission

Orbit

ERS-2 will be in a sun-synchronous, polar, near-circular orbit. Because of the need to phase ERS-2 with ERS-1, which will be used for cross validation, SAR interferometry, and as an in-orbit spare, there will be only one orbit* with a repeat cycle of 35 days. This orbit has the following parameters:

Semi-major axis	:	7147.191 km
Inclination	:	98.4913 deg.
Eccentricity	:	0.001165
Arg. of perigee	:	90.0 deg
Mean local solar time at asc. node	:	10 h 30 m

The subsatellite track repeatability will be maintained to within ±1 km of the nominal one. This requires orbit correction manoeuvres to be executed. The frequency of these manoeuvres depends upon the solar activity; on average, a manoeuvre is executed once every two weeks. Inclination maintenance, requiring out-of-plane manoeuvres, is expected to occur about twice a year. Apart from the inclination manoeuvres, which take longer, normal attitude should be resumed within two minutes from the beginning of a manoeuvre.

On the basis of tracking information, orbital parameters will be predicted for 16 orbits (about one day) in advance with the accuracies as per Table 2.3-1.

3 σ accuracy	position [m]	velocity [mm/s]
radial	28.5	954.3
along track	913.5	28.5
across track	14.7	15.3

Table 2.3-1 Orbit Prediction Accuracy

After the satellite has actually passed the tracking station and actual measurements have been evaluated, the orbit is restituted with the accuracies as per Table 2.3-2.

* **Note:** ERS-1 had several orbits with different repeat cycles to optimise the orbit for certain investigation phases: Venice orbit, ice phase, multidisciplinary phase, geodetic phase.

3 σ accuracy	position [m]	velocity [mm/s]
radial	25.2	39.3
along track	57.3	26.4
across track	13.8	14.4

Table 2.3-2 Orbit Restitution Accuracy

Note: The processing delay will determine which of the above orbit information will be used for the processing of GOME data; for normal off-line data, the restituted orbit will be used.

Attitude

ERS-2 is a three-axis stabilised satellite with local normal pointing, i.e., the Nadir axis (-z axis) will be controlled such that it is normal to the Earth reference ellipsoid model stored onboard.

Normally, ERS-2 will be in "Yaw Steering Mode" (YSM), in order to compensate for the Earth's rotational velocity. This means that the satellite is continuously rotated about the yaw (z) axis, depending upon the position of the satellite with respect to the Earth. Figure 2.3-3 shows the yaw steering angle as a function of the orbit fraction.

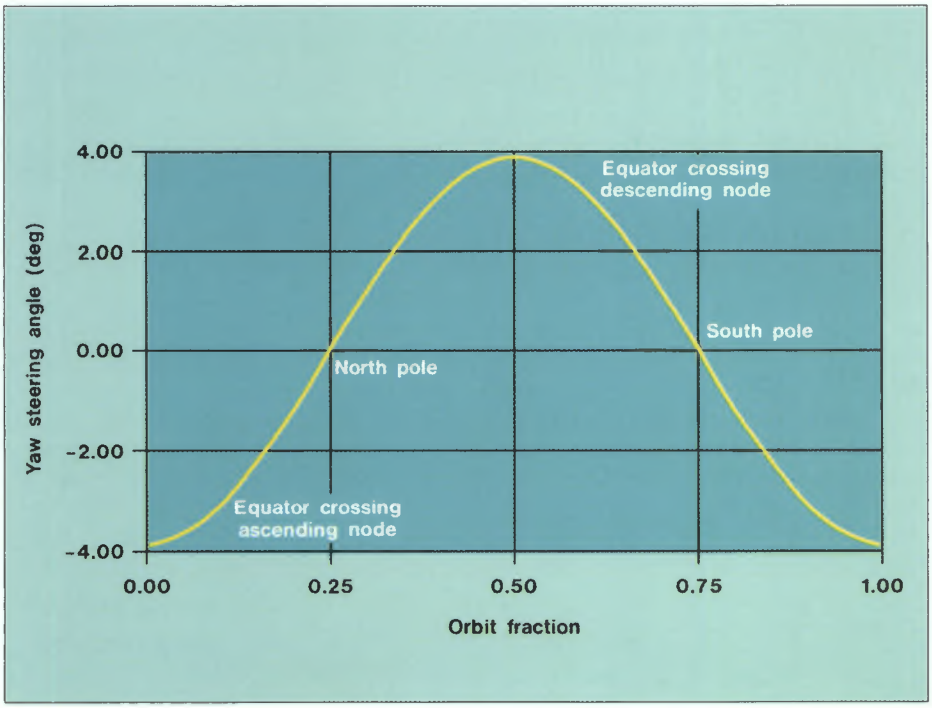


Figure 2.3-3 Yaw Steering Angle

The satellite's Attitude and Orbit Control System (AOCS) provides attitude and attitude rate stability as per Table 2.3-4.

	X (roll)	**Y (pitch)**	**Z (yaw)**	
Maximum Bias	0.11	0.11	0.21	deg
Maximum Random Harmonics	0.03	0.03	0.07	deg
Maximum Rate Error	0.0015	0.0015	0.0015	deg/s

Table 2.3-4 Attitude and Attitude Rate Errors

3. Main Instrument Requirements

This chapter summarises the Main Instrument Requirements as applied to the Flight Model. Note that compared to some previous publications (e.g., /6/), some parameters have been updated as result of the BBM testing.

band	1A	1B	2	3	4
parameter					
spectral coverage [nm] (1)	240-307	307-316	311-405	405-611	595-793
spectral resolution [nm] (1)	0.20	0.20	0.17	0.29	0.33
signal to noise ratio (for integration times) (2)	10-434 (30 sec)	434-841 (1.5 sec)	849-5100 (1.5 sec)	3500-4200 (1.5 sec)	3239-4214 (1.5 sec)
pupil area [cm^2]	0.98	0.98	0.98 (3)	0.215	0.215
optical efficiency [%]	15-27	15	6-14	10-15	5-10

Table 3-1 GOME Optical Performance Key Parameters

The band boundary between bands 2A and 2B can be set via software for any meaningful pixel between 311 and 405 nm. At present, the baseline is to use no separation in channel 2.

(1) In vacuum at 20.0 deg.

(2) For signal fluxes as computed with LOWTRAN.

(3) At 320 nm. An asymmetric diaphragm located in channel 2 reduces the flux at longer wavelengths linearly from 1 at 320 nm to 0.6 at 400 nm.

On-chip Integration Times:	Commandable in multiples of 93.75 ms, independently for each band.
Analogue-Digital Conversion:	16 bit resolution.
Readout Interval:	One readout is transmitted every 1.5 sec. Longer integration times are filled with dummy data. Shorter readout times are transmitted only once per 1.5 sec.
Noise (at -38°C):	Less than 2000 e, i.e., 2 Binary Units.
Dynamic Range:	< 60.000 BU (depends on saturatiocharge Reticon detector, specified >9 pC).
Linearity:	Better than 0.01% full-scale after offset correction and calibration.

Instantaneous Field of View:	2.9 x 0.14° (along x across track)
Scan Swath:	Selectable between: ± 4.390° (corresponding to 120 km on ground) ± 8.725° (corresponding to 240 km on ground) ± 12.940° (corresponding to 360 km on ground) ± 16.990° (corresponding to 480 km on ground) ± 30.976° (corresponding to 960 km on ground)
Center Line of Swath:	Nominally 0° (Nadir direction), but programmable bias (e.g., for polar swath) within the total clear FOV.
Total Clear FOV:	From -48.073° to +85° Note: A range from +70° to +85° is foreseen for moon observations.
Static Pointing:	Commandable anywhere within the Total Clear FOV; plus fixed positions for lamp and diffuser views.
Static Pointing Accuracy:	Better than 0.06° optical.
Scanning:	Full forward scan for any of above swaths within 4.5 sec. Flyback within 1.5 sec. Note: Forward scan of 4.5 sec is subdivided into three periods of 1.5 sec each, corresponding to an on-ground pixel size of 40 km x 320 km for the maximum scan swath.
Scanning Telemetry:	14 bit at 10.67 Hz, included both in S-band and X-band.

4. The GOME Instrument Design

4. The GOME Instrument Design

4.1 Overall Architecture

In principle, GOME is a **spectrometer**, in which light arriving from the sun-illuminated atmosphere is dispersed and sensed by four individual channels, each equipped with its own **Focal Plane Assembly.** In order to sweep the instantaneous field of view over a wide angle in the across-track direction, a **Scan Unit** is used. This also provides the possibility to view a **Calibration Unit,** which is equipped with a calibration lamp for wavelength calibration and a sun diffuser for direct sun viewing. Because the instrument is sensitive to the polarisation state of the incoming light, a **Polarisation Unit** measures the degree of polarisation in three broadband channels. All these units are mounted on an optical bench **Structure**, which also has **Thermal Control**. Finally, all electrically active elements are supplied and controlled by the **Detection and Data Handling Unit**, which in turn interfaces with the **Digital Electronics Unit** of the ATSR instrument (see Chapter 1.2). Figure 4.1-1 gives an overall block diagram of the GOME instrument. The highlighted subsystems are described in detail in the following chapters. Figure 4.1-2 shows the assembled instrument, with the MLI removed, during the instrument level vibration test.

4.2 Spectrometer Optics

From an optical point of view, GOME is a double spectrometer. A quartz prism produces a moderate spectral dispersion, which is split into four channels. High dispersion is obtained by means of diffraction gratings in each of the fours channels. A functional block diagram of the optical system is shown in Figure 4.2-1.

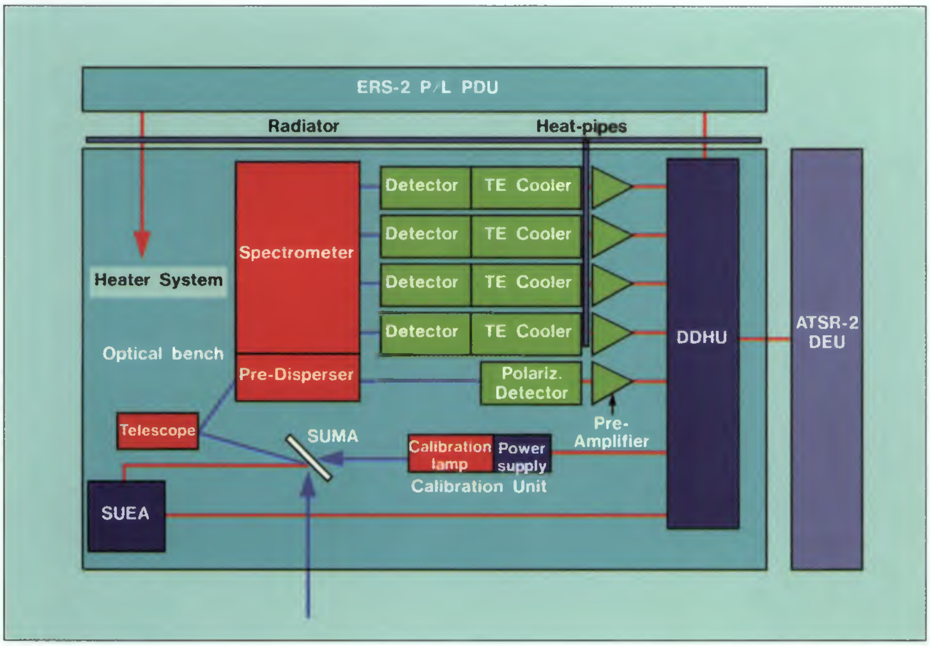


Figure 4.1-1 Block diagram of the GOME instrument

Figure 4.1-2 GOME instrument package with MLI removed

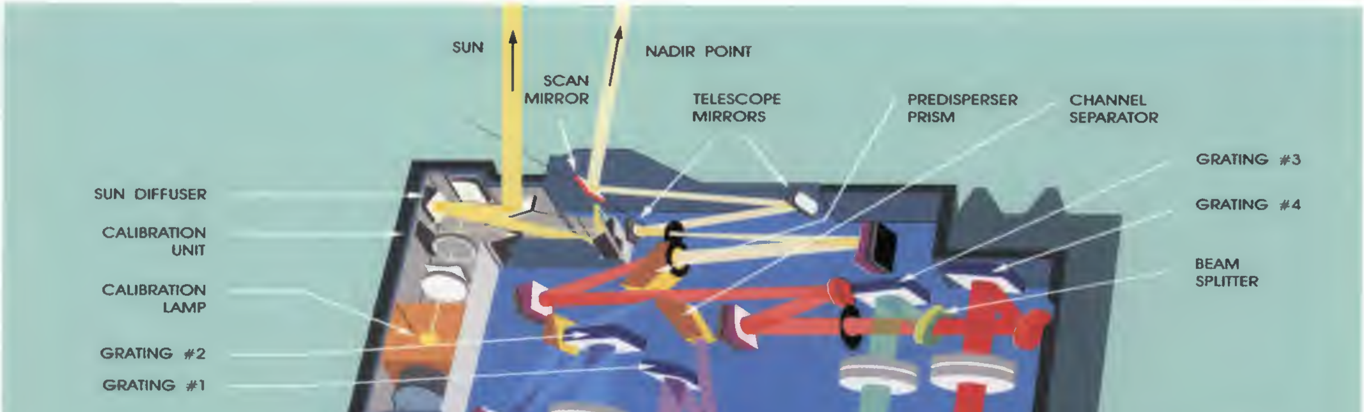


Figure 4.2-1 Functional block diagram of the spectrometer optical system

Figure 4.2-2 Slit (in its support)

The first optical element is the scan mirror, which reflects the optical beam into the telescope, focusing it on the spectrometer slit. The diverging beam is then collimated by an off-axis parabola and is dispersed in the predisperser prism. The low dispersion spectrum is then focused onto the channel separator, which provides the separation between channels 1 and 2 by a combination of reflecting and transmitting coatings. The long wavelength part of the spectrum passes the channel separator unaffected and is split between channels 3 and 4 by a dichroic filter. Each individual channel consists of a diffraction grating and an objective which focuses the dispersed spectra on the detectors, housed in their Focal Plane Assemblies. By setting the scan mirror to the proper position, it is possible to insert the signals coming from the Calibration Unit (see Chapter 4.4 for details).

At the predisperser prism, light, with the polarisation plane parallel to the entrance slit, leaks out at the backside and is channelled to a detector with three spectral bands corresponding to about the spectral ranges of channels 2, 3, and 4 (see Chapter 4.5).

The individual optical elements are described in more detail:

Scan Mirror

The scan mirror is made of aluminium with nickel plating and an MgF_2 coating optimised for best efficiency in the UV. The mirror is bonded to the scan axis. (See Chapter 4.6 for details of the mechanism.)

Telescope and Slit

The beam coming from the scan mirror is focused by an anamorphous telescope formed by two cylindrical mirrors onto the spectrometer slit. The first cylindrical mirror has a focal length of 200 mm in the plane parallel to the slit height, while the second one has a focal length of 40 mm in the plane perpendicular to the slit. The slit has dimensions of 10.15 mm x 0.10 mm. The focal lengths of the cylindrical mirrors and the slit size define the instantaneous Field of View, which is 2.9 x 0.143 deg. Figure 4.2-2 shows the slit in its support.

Predisperser Prism

The beam coming from the entrance slit is collimated by an off-axis parabola and is limited in size by a circular diaphragm. This circular beam falls upon the predisperser prism, which is a quartz prism with an apex angle of 35°.

The refractive index of quartz is not only a function of wavelength (hence the dispersive power), but also a function of temperature. Comparison of this effect with possible other impacts of temperature change has revealed that the predisperser prism is the element most sensitive to temperature change. Therefore, the temperature at the predisperser prism is measured and forms the reference temperature for the wavelength calibration.

Channel Separator Prism and Dichroic Filter

The dispersed, collimated beam leaving the predisperser prism is focused by another off-axis parabola onto the edge of the channel separator prism. Part of the front surface of this prism is supplied with a reflective coating, which reflects the impinging part of the spectrum into channel 2. The other part of the front surface is anti-reflection coated; the part of the spectrum impinging on this surface is channelled internal to the prism into channel 1. The long wavelength part of the spectrum, corresponding to channels 3 and 4, passes the beam separator unaffected. The edge of the beam separator prism can be seen in Figure 4.2-3, just at the right margin.

The separation between channels 3 and 4 is made by means of a dichroic filter, which reflects channel 3 and let pass channel 4. The transmission curve of the dichroic filter is shown in Figure 4.2-4.

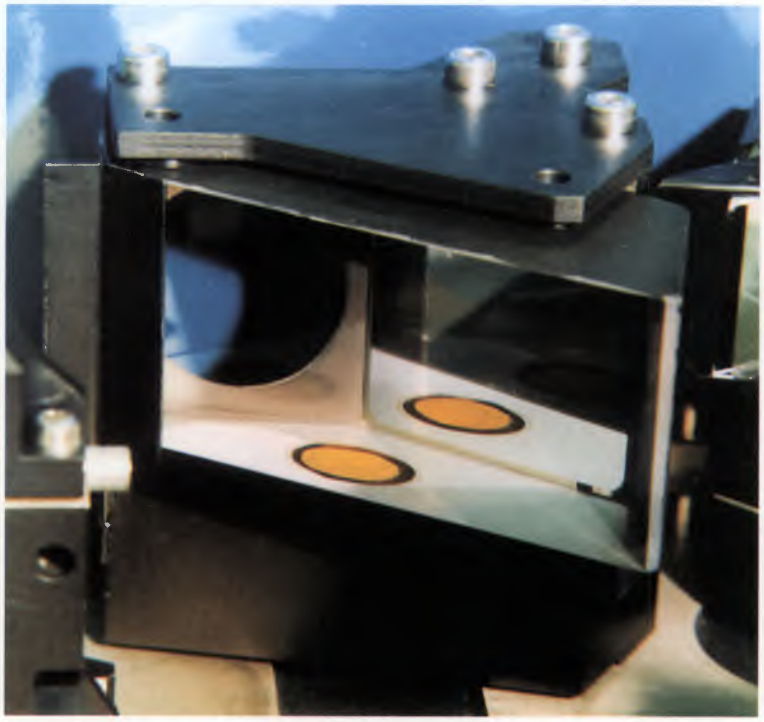


Figure 4.2-3 Channel Separator Prism and Dichroic Filter

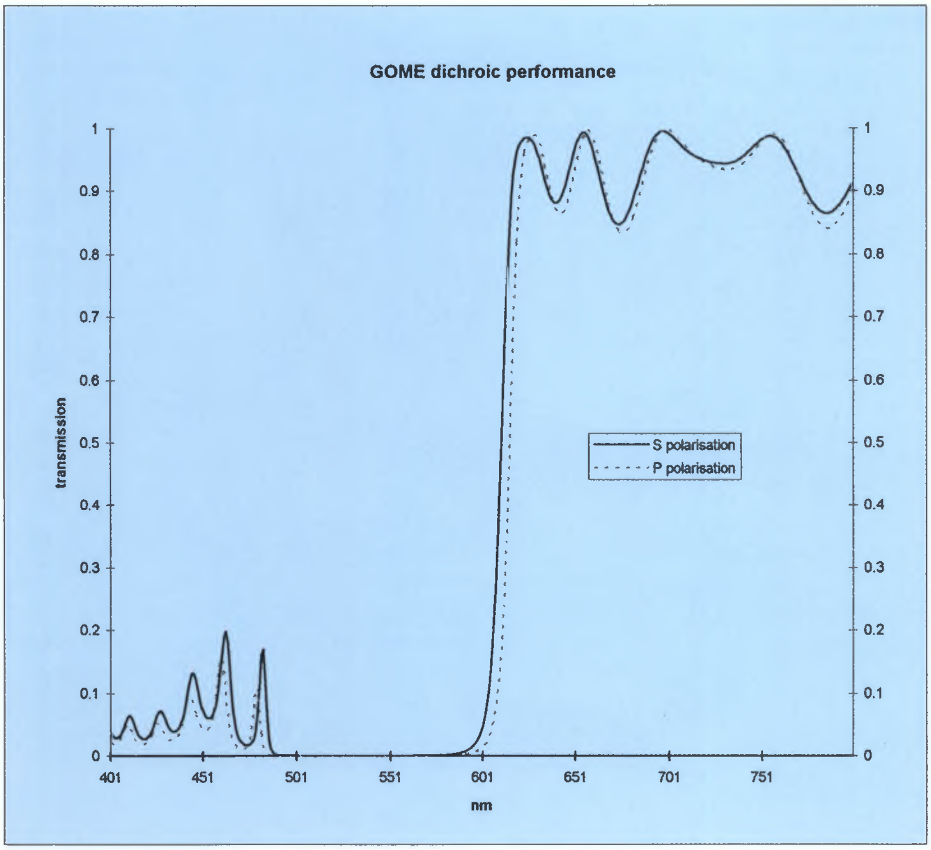


Figure 4.2-4 Transmission curve of the dichroic filter

Spectrometer Channels

The light corresponding to **channel 1** is transmitted through the channel separator prism, collimated by a parabola, diffracted by the flat diffraction grating, and finally focused by the objective with F-number 2 onto the detector housed in this Focal Plane Assembly.

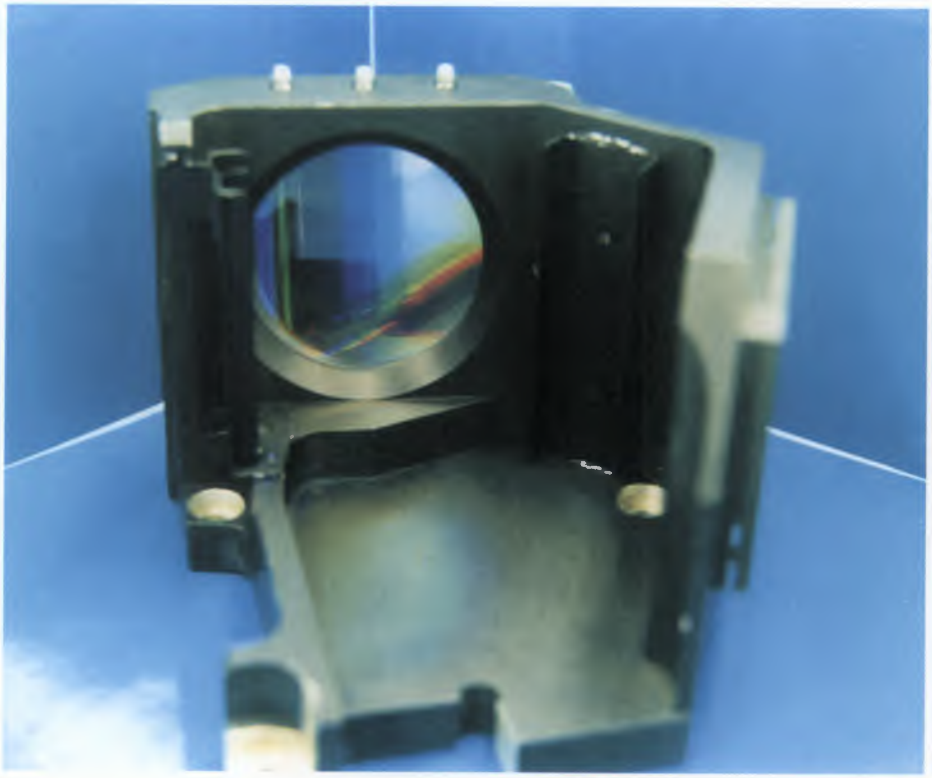
The light of **channel 2** is reflected at the channel separator, folded by the beam folding prism, collimated by an off-axis parabola, diffracted by the grating and imaged by the objective with F-number 2 onto the detector.

The long wavelength light corresponding to channels 3 and 4 passes the channel separator unaffected, is reflected by a flat mirror, collimated by an off-axis parabola and limited in diameter by a diaphragm. It then reaches the dichroic beamsplitter at an angle of 19.5 deg. with respect to the normal.

The light reflected into **channel 3** is diffracted by the grating and then focused by the objective with F- number 3 onto the detector.

Channel 4 is composed of a flat mirror, the diffraction grating, and the objective with F-number 3. Figure 4.2-5 shows the flat mirror and the diffraction grating of channel 4.

Figure 4.2-5 Channel 4 flat mirror and diffraction grating



Gratings

All gratings are flat holographic master gratings used in first order, blazed for maximum efficiency, and selected for minimum stray light performance. The substrate onto which the hologram is developed was selected such as to compensate for certain temperature effects. Table 4.2-6 shows some key parameters for the gratings employed in the four channels.

Channel Number	Lines (mm)	Clear Aperture Diam. (mm)	Blank Material (SCHOTT)	Wavelength Range (nm)
1	3600	35	K10	239-316
2	2400	50	ZKN7	311-405
3	1200	44	BK10	405-611
4	1200	44	ZKN7	595-793

Table 4.2-6 Key parameters for gratings employed in the four channels

Objectives

All objectives are four quartz lens achromats, housed in a titanium tube to minimise de-focusing due to changing temperatures. The objectives have flanges at the rear side to which the Focal Plane Assemblies are attached and aligned. Each objective carries a set of redundant Light Emitting Diodes (LEDs). The diodes illuminate the detectors and can be used for test purposes. Figure 4.2-7 shows the objective of channel 4, as an example.

Polarisation Optics

At the predisperser prism, the light polarised parallel to the slit is reflected internally to the prism, and does not leave the prism at the Brewster angle. This light is internally reflected at the third surface of the prism and then exits. This fraction of light is used to monitor the polarisation state of the incoming light, by focusing it by using an off-axis parabola (not shown in the optical scheme), deflecting it out of plane with a plane mirror, and then detecting it in three broadband channels with the polarisation unit. (See Chapter 4.5 for details).

Calibration Optics

The calibration unit, which has its own self-standing optics, is optically interfaced to the spectrometer by driving the scan mirror to the appropriate position. (See Chapter 4.4 for details.)

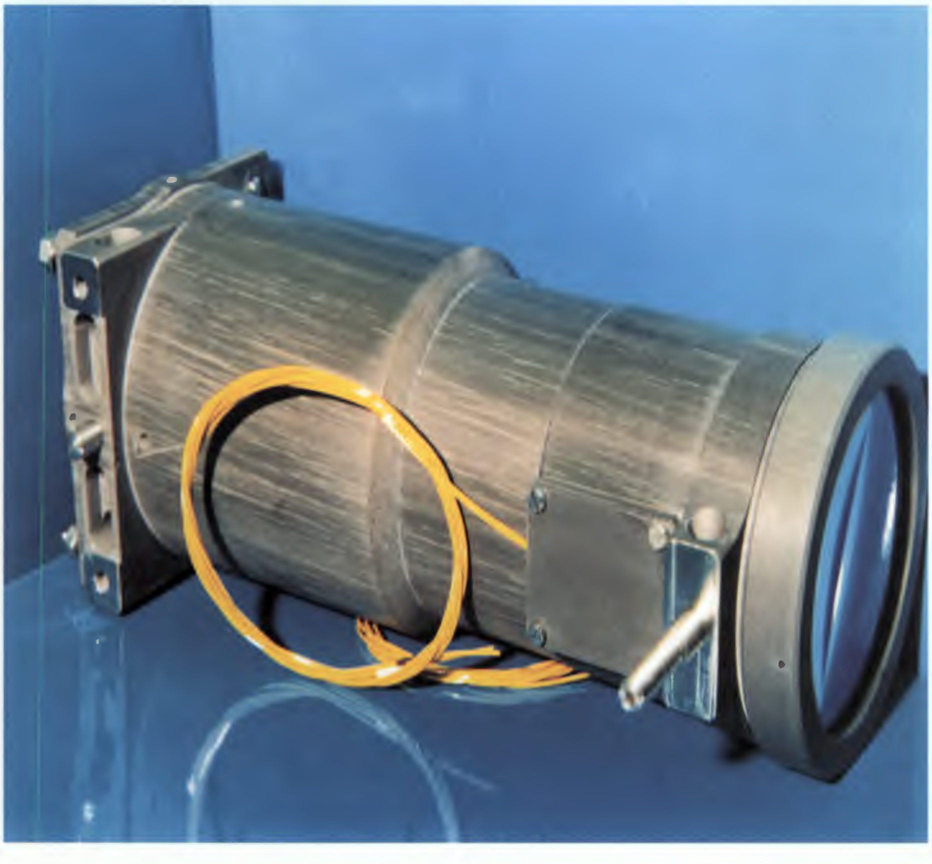


Figure 4.2-7 Objective of channel 4

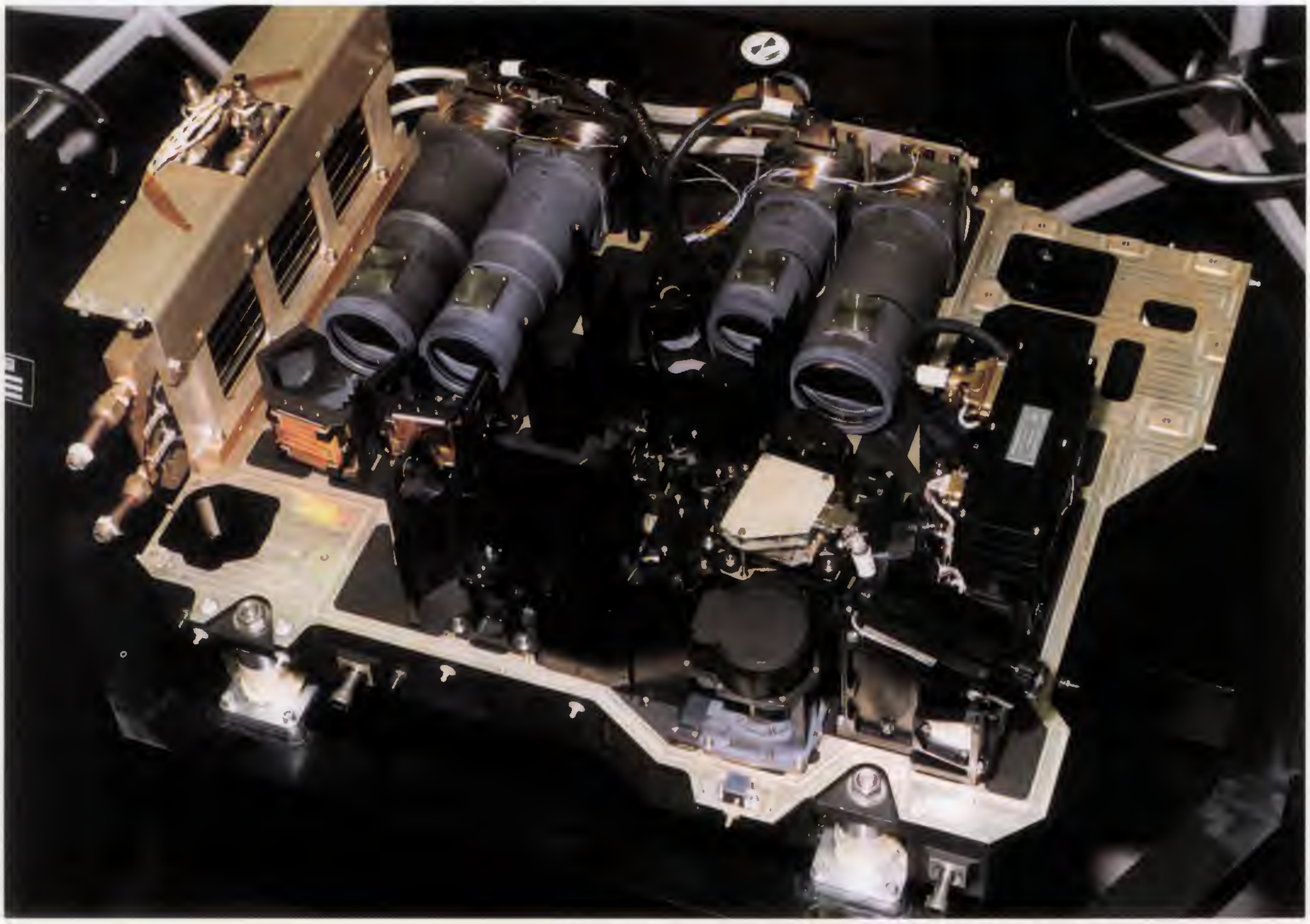


Figure 4.2-8 Partial view of calibration optics during assembly stage

Figure 4.2-8 gives a partial view of the optics during the assembly stage. This photograph gives an impression of the high packing density of the optics, which is even further increased by the numerous baffles installed to suppress external and inter-channel stray light.

4.3 Focal Plane Assemblies

Each Focal Plane Assembly (FPA) consists of a number of elements:

- the detector
- the Peltier coolers
- the "pin plates" to which the Peltier element and detector are mounted
- the charge amplifier printed circuit board
- the housing with its connection to the thermal control system, mechanical attachment to the objectives, and the pipe connection to the evacuation system.

All these elements are described in detail in text that follows.

Detectors

The detectors are Reticon RL-1024 SRU-type linear array silicon detectors, with 1024 pixels of size 25 µm (in dispersion direction) by 2.5 mm (in the along slit direction). In principle, each diode of the array can be addressed individually; in GOME, however, only the detectors of channels 1 and 2 are split into two virtual bands which can have different integration times and readout cycles. The physical dimensions of the detector are 42.7 mm x 15 mm x 1.9 mm, with the light-sensitive area being 25.6 x 2.5 mm. The light sensitive area is covered by a 3 µm-thick SiO_2 protective layer; the window covering the commercial units has been removed. Instead, an additional ceramic baffle is attached to the top surface of the detector package. Table 4.3-1 provides some key characteristics of the detectors. Figure 4.3-2 shows a detector. Although the detector has some built-in temperature sensors, these are not being used. Instead, AD590 temperature sensors are glued to the bottom side of the detectors at either end.

number of pixels	1024
pixel size	25 µm x 2.5 mm
saturation charge	> 9 pC
quantum efficiency at 254/365/750 nm	> 30/55/65 %
dark current (each pixel)	< 0.5 fA at -38°C
efficiency non-uniformity	< 10 %
linearity errors	< 0.1 %

Table 4.3-1 Key Characteristics of the Detectors

Peltier Elements

The Peltier elements (also called thermoelectric coolers or heat pumps) are two-stage coolers based upon the Marlow-type SP 1548, with the two stages electrically in series. The detector is glued to the top stage, while the bottom stage is brazed to the copper dowel of the pin plate. These coolers can provide a maximum delta temperature between hot and cold side of 60°, when loaded with 300 mW. The Peltier elements are driven in closed loop by the DDHU (see Chapter 4.8) with the AD 590 attached to the detectors as sensors. Maximum electrical ratings are 5 V and 1.2 A; overall efficiency is better than 10%.

Pin Plates

The pin plates provide the mechanical support to the detector / Peltier group, thermal connection to the Peltier hot side, and electrical supplies to the detector, temperature sensors, and Peltier element.

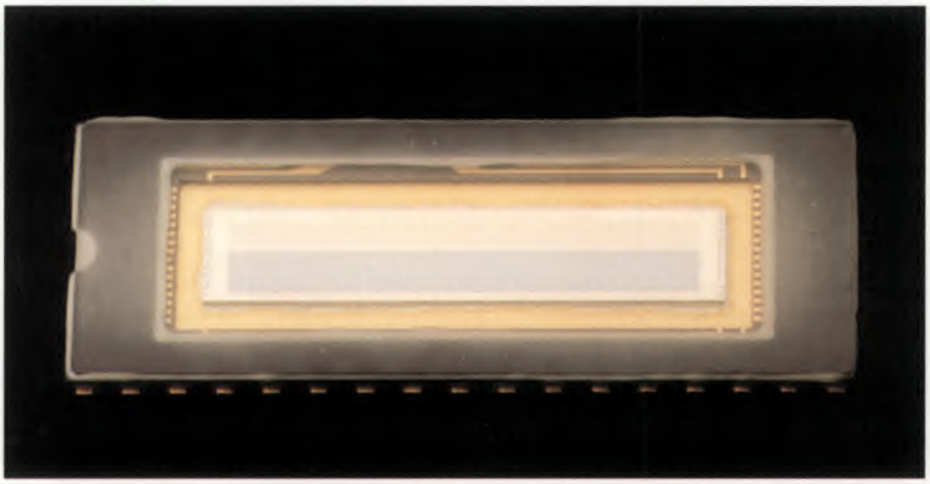


Figure 4.3-2 Reticon RL-1024 SRU-type linear array silicon detector

The hot side of the Peltier element is brazed to a copper dowel which has nearly the same surface area as the bottom stage of the Peltier. The dowel reaches through to the backside of the FPA housing where it is attached to the heat pipes (see Chapter 4.7).

In order to account for the different focal positions for different wavelengths, the detector planes are tilted with respect to the normal to the optical axis. The angles are different for each channel.

channel	angle
1	-9.55°
2	+5.72°
3	-3.50°
4	-1.45°

The copper dowel is interfaced with the titanium plate which contains 38 electrically-isolated, vacuum-tight feedthroughs. Figure 4.3-3 shows a side view of the pin plate with the Peltier element installed, but without detector. Figure 4.3-4 shows the back side of a pin plate.

Charge Amplifier PCB

A printed circuit board (PCB), which carries the preamplifier, is mounted at the back side of the pin plate. This is a low noise amplifier and a dual FET input stage. The preamplifier converts the charge collected by the diodes of the Reticon array into a voltage which is then transmitted to the Analogue Processing Module Board of the DDHU (see Chapter 4.8).

FPA Housing

The overall FPA is comprised of two compartments: one which houses the detectors and Peltier elements, and one which houses the preamplifier PCB.

Figure 4.3-3 Side view of pin plate with Peltier element

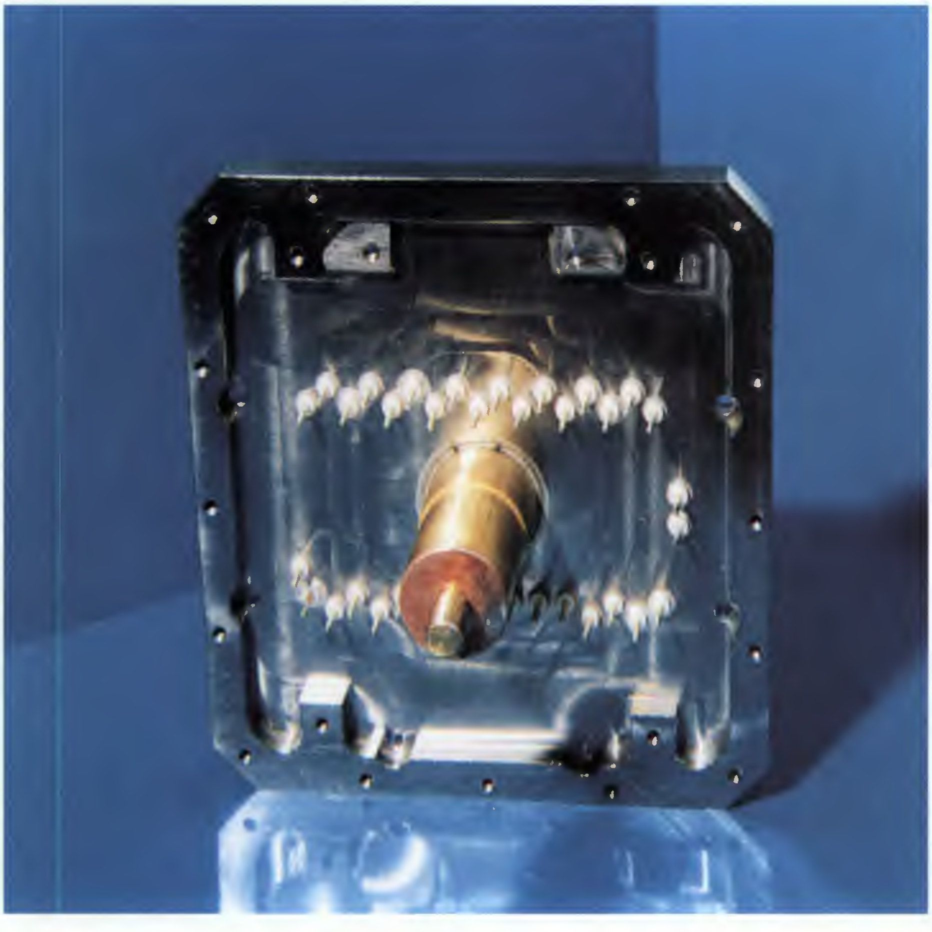


Figure 4.3-4 Back side view of a pin plate

Figure 4.3-5 Schematic cross-section of the FPA

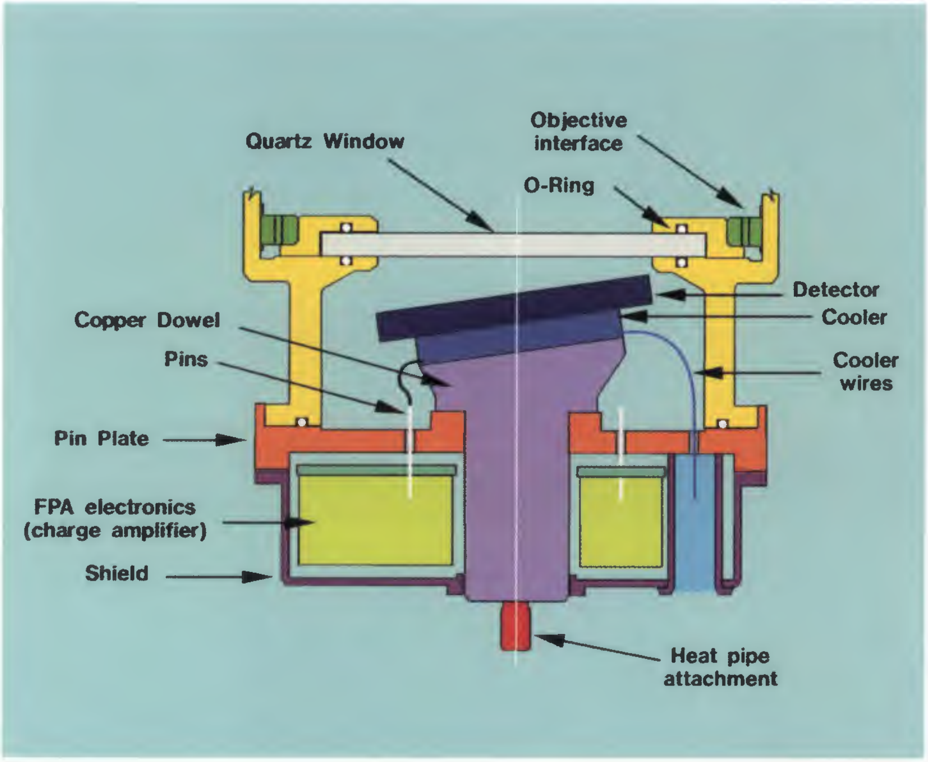


Figure 4.3-6 FPA attached to the objective

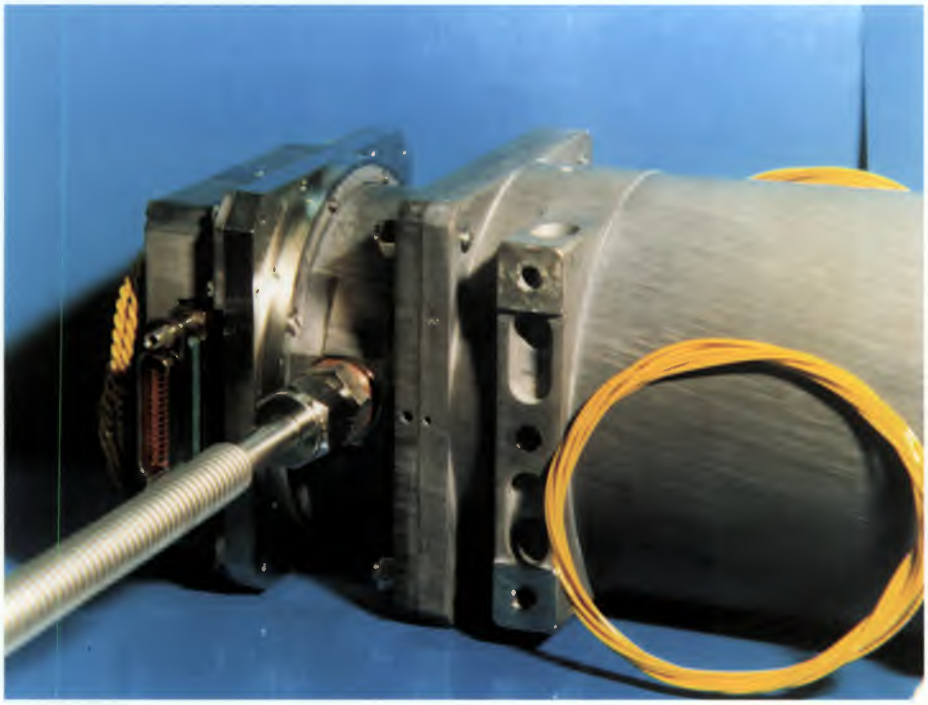


Figure 4.3-7 Bottom view of FPA, attached to the objective

The detector compartment is vacuum-tight and has a quartz window on the side towards the objective. All elements are sealed by O-rings. At the front side, the FPA is flanged to the objective.

The pin plate is the interface between the vacuum-tight detector compartment and the preamplifier compartment. The preamplifier compartment provides the electrical interfaces to the DDHU, separate for the detector and temperature sensor signals, and the supply lines for the Peltier cooler.

The FPA housing is constructed of titanium. Figure 4.3-5 shows a schematic cross-section of the FPA. In Figure 4.3-6, the FPA is shown from the side where it is attached to the objective. Figure 4.3-7 shows a bottom view of the FPA attached to the objective.

4.4 Calibration Unit

The calibration unit provides the means to perform the in-orbit calibration of the GOME instrument for both wavelength and radiometric calibration. The wavelength calibration is provided by a **calibration lamp**, powered by its **power supply**. The radiometric calibration is achieved by looking at the sun via a **diffuser**, which is protected by a **shutter**. Both paths have a number of **optical** elements which also enable to monitor the diffuser.

Calibration Lamp

The calibration lamp is a hollow cathode gas discharge lamp with a neon gas fill and a Pt/10% Cr alloy electrode. This lamp provides a number of atomic emission lines of the three elements (Pt, Cr, and Ne), which are sufficiently well distributed over the spectral range covered by GOME. Figure 4.4-1 shows the lamp spectrum as recorded with the instrument. A similar lamp, without the Cr addition to the electrode, had flown on previous space missions /2/. In order to select the optimum lines for performing the wavelength determination, the lamp spectra of two of these lamps have been measured at high resolution /3/ with a Fourier Transform Spectrograph and then convoluted to the GOME resolution. In another test programme, several lamps have been operated, either continuously or with a switched duty cycle of 50%, to demonstrate the suitability for long-term operations. Degradation after 500 burning hours has been moderate and shows the compatibility of the selected lamp type with the mission requirements.

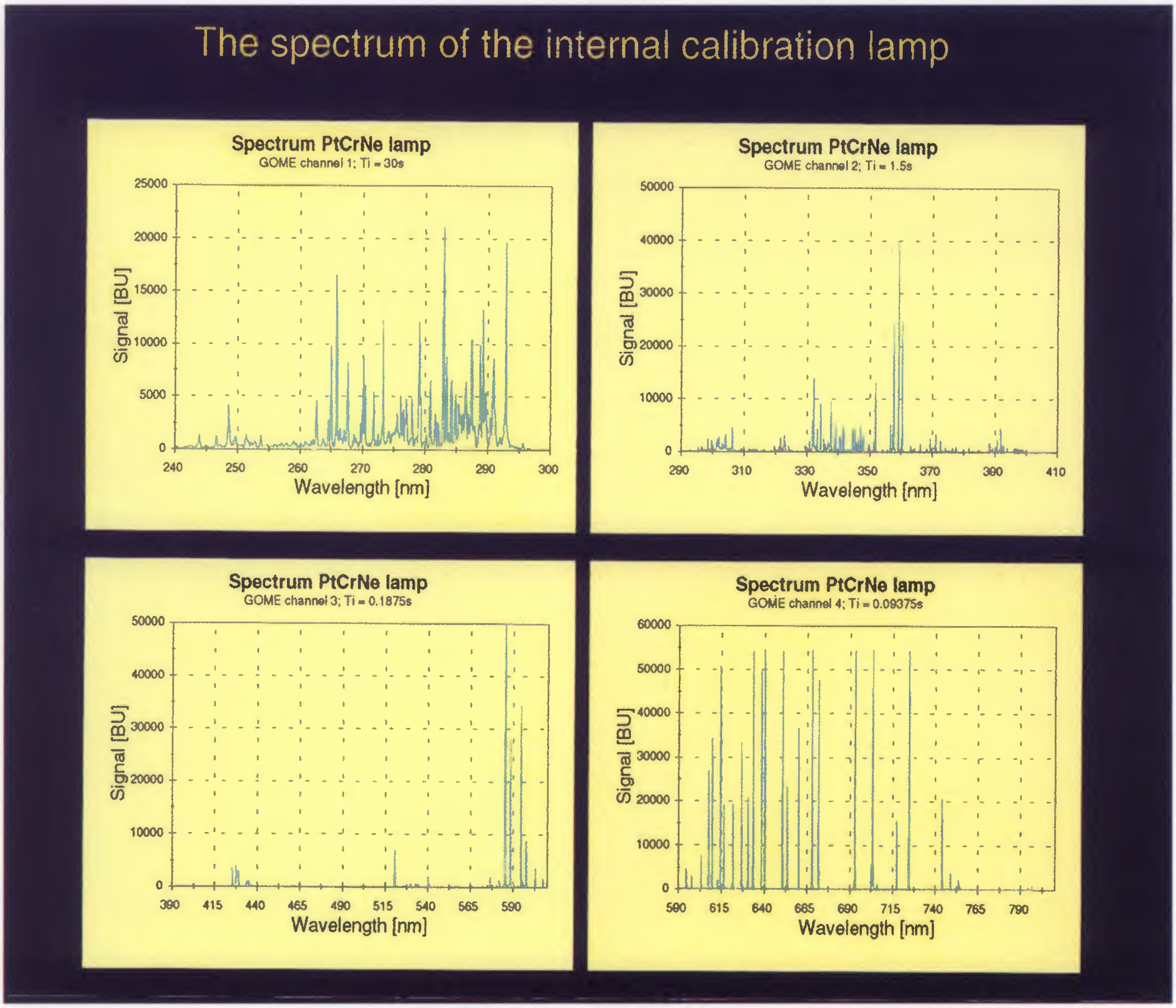


Figure 4.4-1 Calibration lamp spectrum as recorded by GOME

Figure 4.4-2a   Bare calibration lamp

Figure 4.4-2b   Calibration lamp with its mount

The lamp is mounted using a glued-on pyrex ring, onto which flexible blades snap on. Figure 4.4-2a shows the bare lamp and Figure 4.4-2b the lamp with its mounting support.

Lamp Power Supply

The calibration lamp is supplied by its own power supply, which is activated by the DDHU by switching the appropriate relay. Once power is applied, the voltage to the lamp is raised rapidly up to a maximum of 400 V. Once the lamp has ignited (the usual ignition delay is less than 10 s), the power supply regulates the lamp current to 10 mA to stabilise the optical output. This current corresponds to a voltage of about 200 V, resulting in a net power consumption of the lamp of about 2 W. Lamp and power supply together consume less than 5 W of electrical power. Information of the lamp current and voltage, as well as the temperature of the power supply, is provided in the telemetry.

Diffuser

For the purpose of calibrating GOME, the sun can be considered as a stable radiometric calibration source /4/. The problem is that not only does the sun's relative position to the GOME instrument change continuously during one orbit, but it also changes during the year with the seasonal variation in the Earth-sun distance. Figure 4.4-3 shows a plot of the sun's angular position with respect to the GOME coordinates. In order to avoid a complex mechanism to acquire and follow the sun, a diffuser is used to illuminate the instrument with the solar flux. The angular range for which this can be done is indicated in Figure 4.4-3. The diffuser itself is made out of wet sand blasted aluminium, which has been vacuum-coated with 5 nm Cr/100 nm Al. (See Chapter 6 for the diffuser's properties.)

The signal coming from the sun is several times higher than the signal coming from the Earth. In order to attenuate the solar signal such that it does not saturate the detectors, a mesh, with a transmission of 20%, is applied in front of the diffuser. The diffuser proper is shown in Figure 4.4-4.

Shutter

American experiences with a similar concept for radiometric calibration by means of a diffuser have shown that the diffuser is subject to significant degradation if permanently exposed to the sun /5/. So, next to the mesh which already provides a certain degree of protection, a shutter is placed in front of the diffuser aperture to protect the diffuser during periods when no sun calibration is performed. It also prevents stray light from entering through that path.

The shutter is a metal cylinder with an oval hole normal to the cylinder axis, corresponding to the sun FoV. This cylinder is suspended by two bearings and is rotated by means of a two-pole torque motor. A spring acting on a square section of the cylinder assures that the shutter has only two stable states, open or closed. The appropriate status signal is provided by two Reed switches at the end positions.

Optics

There are two optical paths within the calibration unit: the lamp path and the diffuser path. The lamp path consists of a pair of lenses, which images the lamp arc onto a transmission diffuser. The divergent beam is collimated by an off-axis parabola and is reflected by a tilted flat mirror onto a second tilted flat mirror, which then reflects the beam to the scan mirror.

The diffuser path begins with a rectangular mirror at 57.5° to the optical plane, which is placed immediately behind the shutter and the mesh. The light reflects off

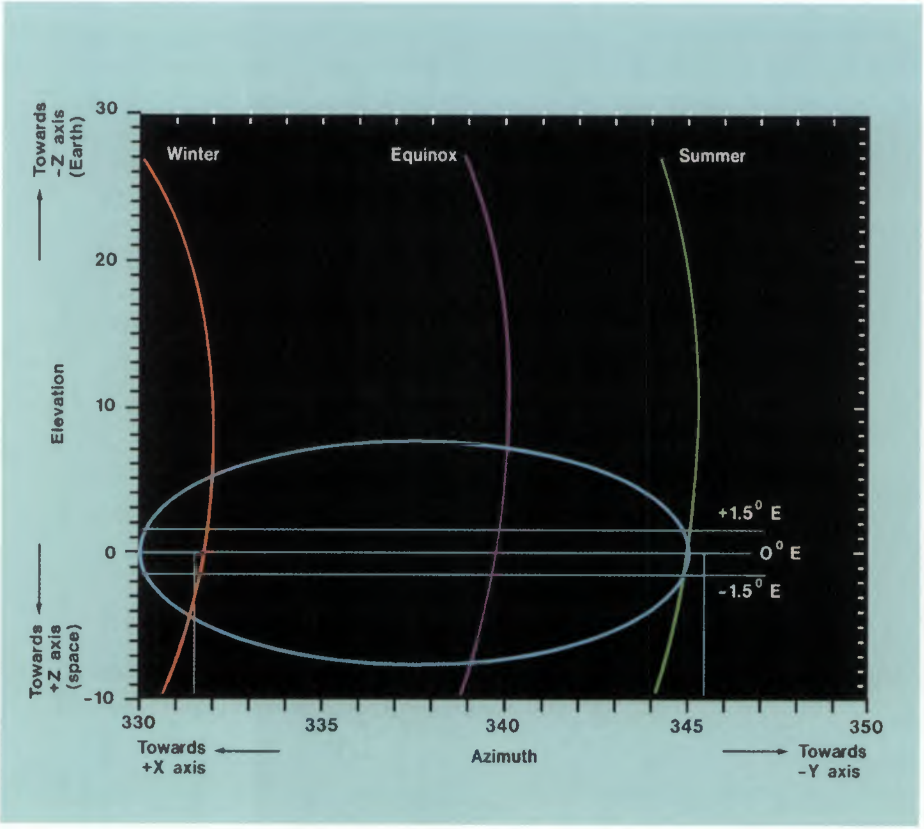


Figure 4.4-3 Plot of sun's angular position with respect to GOME coordinates

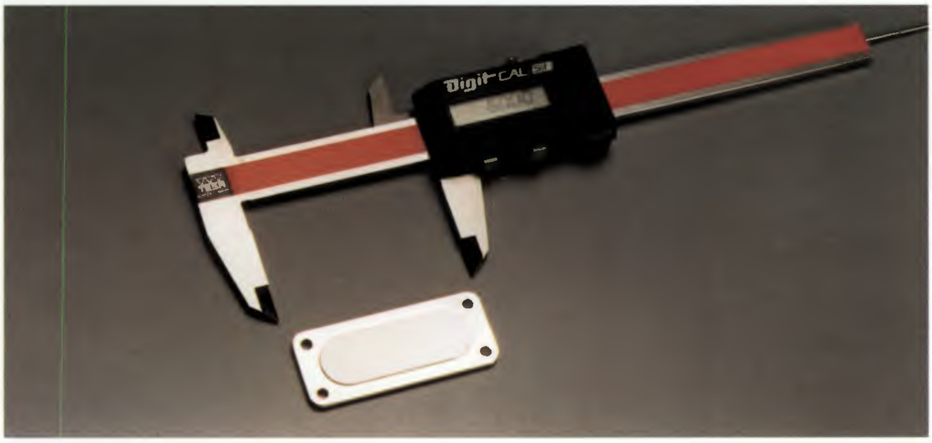


Figure 4.4-4 Diffuser

this mirror and to the diffuser. From there, it is reflected to a mirror placed immediately behind the scan mirror. If the scan mirror is driven to the appropriate position, the light is reflected into the telescope.

A third path provides the possibility of monitoring the diffuser degradation. Of the collimated light reflected off the first flat mirror in the lamp calibration path, half of this beam is picked up by a protruding mirror, "folded" twice, and then reflected onto the diffuser. From there, it follows the sun view. By ratioing measurements of the lamp directly and via the diffuser, the diffuser reflectivity can be monitored at the particular angular situation of the lamp, and at the wavelengths provided by the lamp light. Table 4.4-5 provides the status of the various involved subsystems for the different modes.

Subsystem Mode	Lamp	Shutter	Scan Mirror Position
Wavelength Calibration	on	closed	lamp view
Radiom Calibration	off	open	diffuser view
Diffuser Monitoring	on	closed	diffuser view / lamp view *

Table 4.4-5 : Sub-system Status versus Modes

* *as the monitoring is done by* ***ratioing,*** *both lamp view and diffuser view are necessary.*

Figures 4.4-6 a, b and c show the optical paths for the different views. Figure 4.4-7 shows the assembled calibration unit.

4.5 Polarisation Monitoring Unit

The light reaching the instrument can be partially or completely polarised, or not at all, depending on angular relations, the reflecting/scattering medium, and the wavelength regime. As the response of the instrument is not equal to the two principal polarisation directions of the incoming light (neglecting a priori the possible contribution of circular

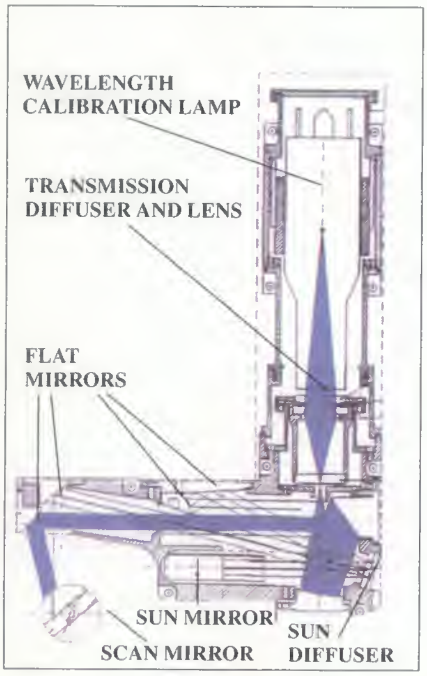


Figure 4.4-6a Lamp calibration path

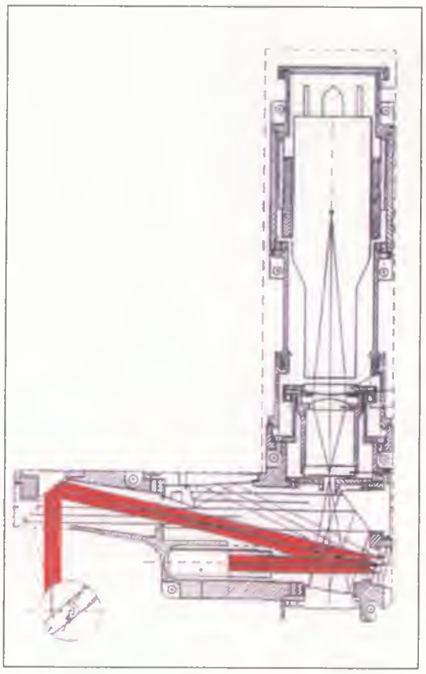


Figure 4.4-6b Sun calibration path

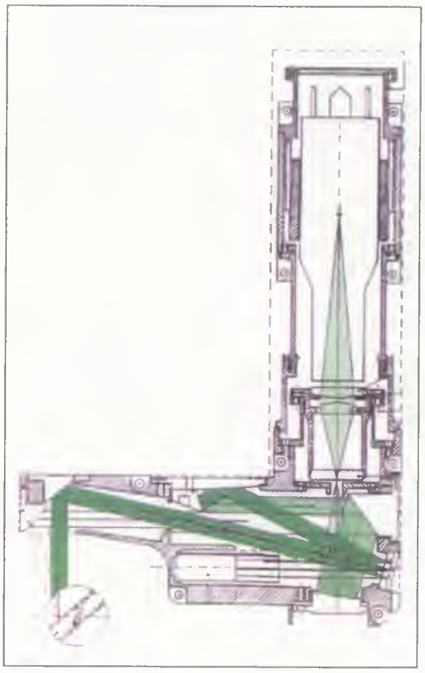


Figure 4.4-6c Optical path for monitoring the diffuser degradation

Figure 4.4-7 Assembled calibration unit

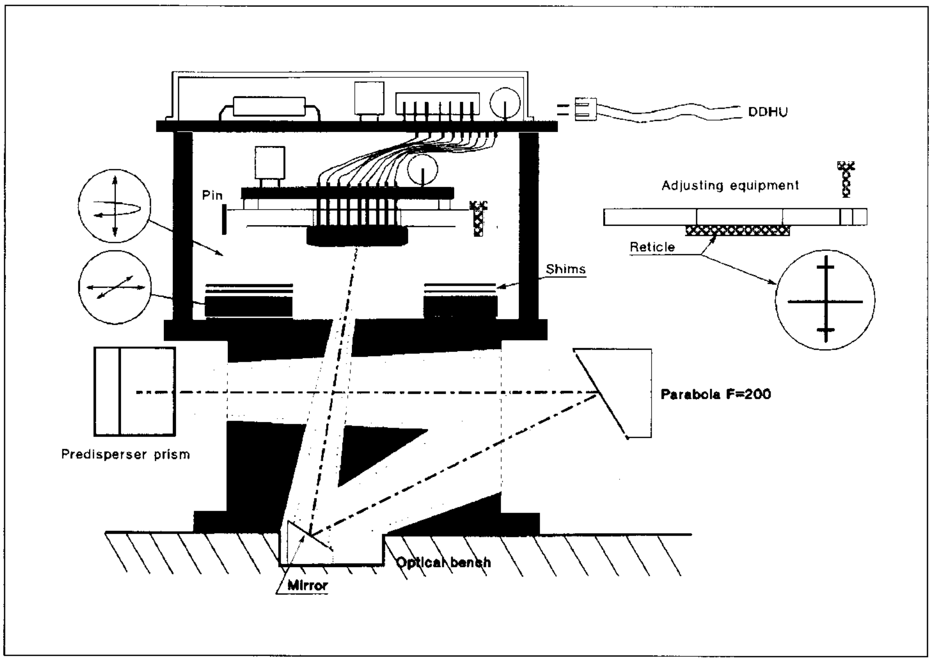


Figure 4.5-1 Schematics of the Polarisation Unit

polarisation, which is assumed to be much less than 1%), there is the need to monitor the polarisation state of the light measured in the main channels. This is done by using the Polarisation Unit*.

Next to the **optical elements**, the Polarisation Unit consists of a **mechanical support** and the **detector hybrid**, which is mounted on a printed circuit board. Figure 4.5-1 shows an overall schematics of the Polarisation Unit.

Optical Elements

The first element in the polarisation monitoring path is the predisperser prism (see Chapter 4.2). There, the collimated light coming from the slit and telescope is wavelength dispersed in a quartz prism. The dispersed light leaves the predisperser at the Brewster angle. Part of the light, however, is reflected internally (back-reflected within the prism) and then leaves at a different position with respect to the main beam. This part is used for the polarisation monitoring, by focusing it with an off-axis parabola and deflecting it below the main optical axis. A flat mirror, lowered into the optical bench, then deflects the beam out of the optical bench, to where the detector is mounted at the focal point of the off-axis parabola.

Mechanical Support

The mechanical support for the detector housing must not only provide the mounting support, keeping clear of all elements of the main optical path, but it also has to provide the apertures for the polarisation beam and the alignment possibilities for the detector with

*The polarisation planes for s and p are defined such that p polarisation is parallel to the long direction of the spectrometer slit (and parallel to the grooves of the gratings) and s polarisation is orthogonal to this.

Figure 4.5-2 Polarisation Unit mechanical support

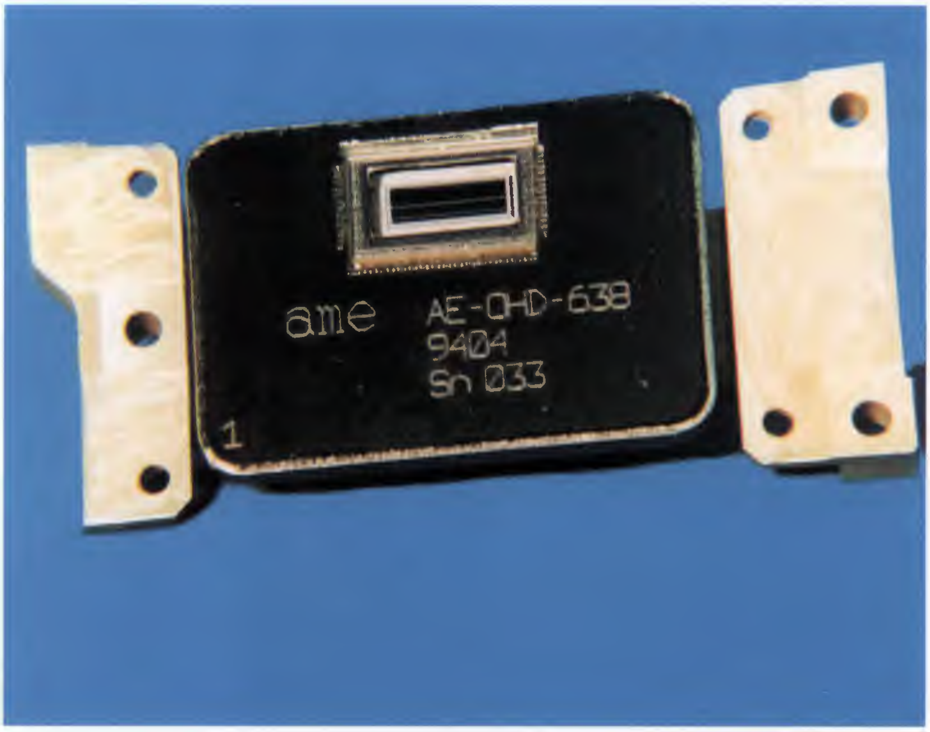


Figure 4.5-3. Detector hybrid for the polarisation detector

respect to the optical beam. Figure 4.5-2 shows the mechanical support of the Polarisation Unit.

Detector Hybrid

The detector is a custom-made hybrid based on silicon photodiodes. Three rectangular areas are sensitive to light in three different broadband wavelength ranges:

UV Band	300 to 400 nm
Visible Band	400 to 600 nm
Red Band	600 to 800 nm

According to the geometry of the optical path and the dispersive power of the predisperser element, the sensitive areas are 1.550, 0.853 and 0.327 mm in width, respectively, and 10.0 mm high. Separation between sensitive areas is 0.060 mm. The sensitive areas are covered by a protective quartz window. Figure 4.5-3 shows the detector hybrid of the polarisation detector.

Next to the exposed detector elements, the hybrid carries a second detector group with the same geometry but not exposed to light. This is used to subtract the dark current of the (uncooled) detector elements and to minimise the effect of temperature variations on the measured polarisation signal. On the same hybrid, low noise preamplifiers, based on the OPA 111- type operational amplifier, are accommodated.

4.6 Scan Unit

The Scan Unit is used to select which light source is imaged on the entrance slit and therefore onto the detectors: the radiance from the Earth, the sun, the moon or the calibration lamp.

The Scan Unit consists of two discrete assemblies: the Scan Unit Mechanical Assembly (SUMA) and the Scan Unit Electrical Assembly (SUEA).

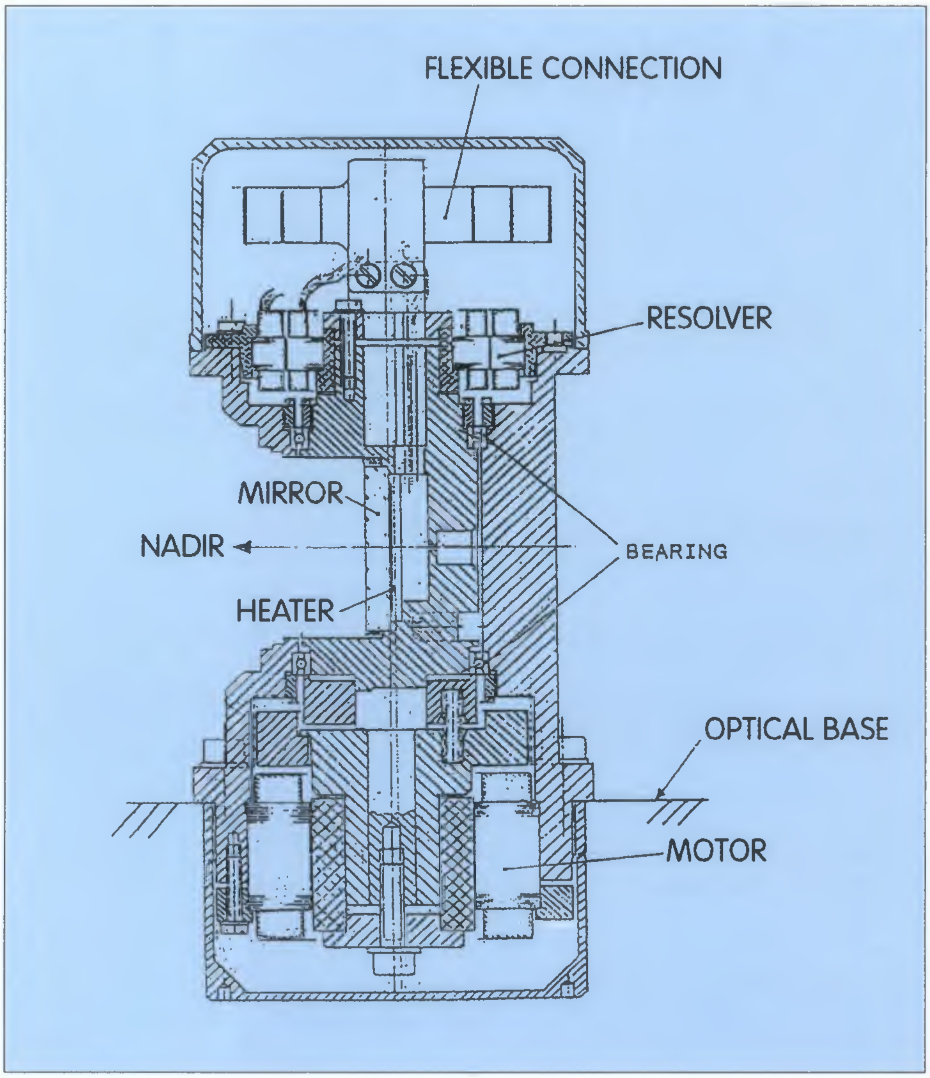
Scan Unit Mechanical Assembly (SUMA)

The Scan Unit Mechanical Assembly, on the optical bench, consists of the **scan axis**, which carries the **scan mirror** proper (see Chapter 4.2), and is supported by the **bearings**. The actuation is done by a brushless **motor**; the rotational movement is sensed by a brushless **resolver**. The whole unit is contained in a **housing** which is aligned on the optical bench. Figure 4.6-1 shows a cross-section of the entire SUMA. The individual elements are described in the following paragraphs.

Scan Axis

The scan axis, oriented along the satellite's direction-of-flight axis (y), is made of titanium. In the centre of the axis, an aluminium scan mirror is glued to its seat. The glue allows for the different thermal expansion coefficients between titanium and aluminium. A heater and a temperature sensor are attached at the rear side of the mirror. Should the need arise, this would permit the mirror to be heated to 75°C to drive off contaminants. Supply to the heater and temperature sensor is via a flexible printed circuit board, which can be wound and unwound depending on the commanded position.

Figure 4.6-1 Cross-section of the SUMA



Within the given constraints of mass and volume, the inertia of the scan axis has been maximised in order to minimise the effect of torque noise produced by the bearings.

Bearings

The scan axis is supported in the housing by two non-separable angular contact bearings, mounted back-to-back for high stiffness and preloaded by a spring. The balls are coated with TiC; the races are dry lubricated with lead. A cage of special design has been fabricated of lead bronze to provide lubrication throughout the life of the hardware. Bearings of this configuration have been life-tested for cycles being equivalent to several times the expected on-orbit life, without any noticeable signs of degradation.

Motor

The motor providing the rotation of the scan axis is a brushless DC torque motor with three-phase supply on eight poles. The permanent magnet rotor and wire-wound stator do

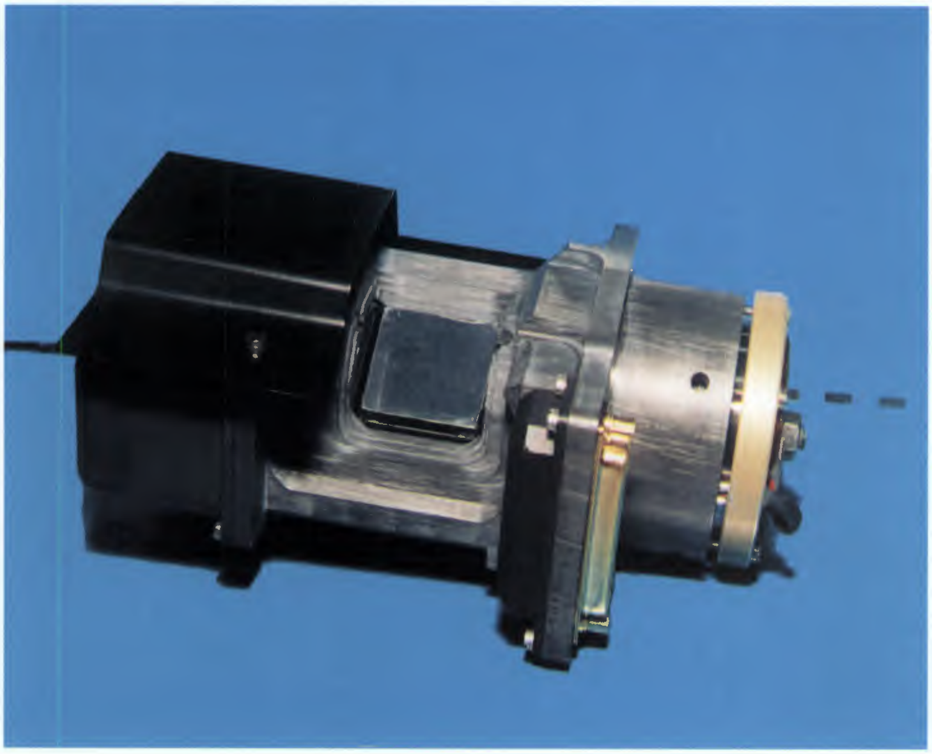


Figure 4.6-2 Assembled SUMA

not require an electrical connection between the static and rotating parts. Peak torque provided is 0.76 Nm. A temperature sensor monitors the motor temperature.

Resolver

The resolver is a rotating transformer, supplied with an AC reference input frequency of 1800 Hz which is derived from the master clock. Two AC signals at the same frequency are output; the amplitudes represent the sine and cosine angles of the shaft position. Supply to the rotor part is through the same flexible printed circuit board, which also supplies the mirror heater and temperature sensor. In order to minimise the potential of EMI, the resolver is mounted at the opposite end of the scanner axis from the motor.

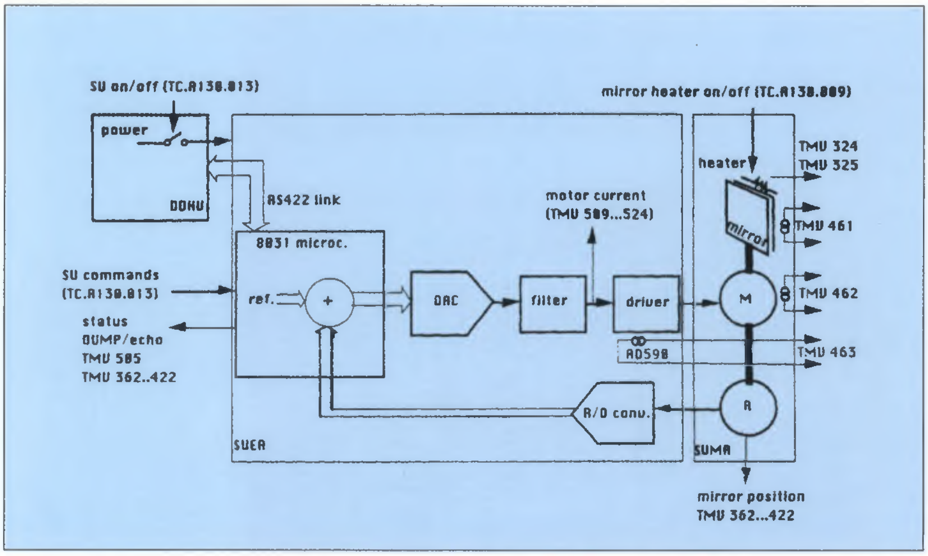
Housing

The SUMA housing is constructed from titanium to match the properties of the axis optimally. It provides the seats for the bearings, motor and resolver stators, and the electrical connections. The central part of the housing recedes such as to provide clearance for the optical paths at all necessary positions. The housing is provided with a flange by which it is mounted and aligned on the optical bench. Figure 4.6-2 shows the assembled SUMA. The electrical connector interfaces via an appropriate harness with the Scan Unit Electrical Assembly.

Scan Unit Electrical Assembly (SUEA)

Figure 4.6-3 shows a block diagram of the SUEA and its interfaces with the DDHU and the SUMA.

Figure 4.6-3 Diagram of SUEA and interfaces with DDHU and SUMA



The entire scan unit is powered through a relay in the DDHU. Mode and position commands are communicated via an RS422 link from the DDHU to the SUEA. From the received commanded position and the sensed actual position of the scan mirror, an 80C31 radiation-hardened microcontroller computes the new position to be achieved. This digital signal is converted into an analogue signal, filtered and then provided to the motor PWM driver, which supplies the appropriate power to the three phases of the motor.

The SUEA also provides the excitation of the resolver at 1800 Hz, which is derived from the master clock. The analogue signals from the resolver are converted into 14-bit resolution digital signals, which are used for control loop computation and as telemetry for the mirror position (see Chapters 7.3 and 7.4).

The electronic circuits are implemented on four printed circuit boards:

- motor driver
- excitation
- microcontroller (with 4k PROM)
- input/output

and are contained in a self-standing box, mounted on the optical bench and supplied with its own thermal control surfaces.

Scan Unit Functions

The Scan Unit has two basic modes of operation:

- static pointing
- scanning

Static Pointing

In principle, the scan mirror can be driven to any static pointing position within the limits of the software stops. (Beyond the software stops, there are hardware stops to prevent damage to the flexible connection between rotor and stator part.) There is a number of discrete positions of interest:

- *Nadir Pointing*

  This measurement position is an alternative to scanning. The scan mirror is positioned such that light from the Nadir direction is sensed. This is also the default position if, 30 sec after power-up of the scan unit, the communications link is not established.

- *Pole View*

  Static position towards the North Pole at 47.620 degrees; static position towards the South Pole at -47.093 degrees.

- *Moon View*

  For calibration purposes, the moon can be viewed at positions between +70 and +85 degrees.

- *Sun View*

  In this mode, the sun can be viewed via the diffuser of the Calibration Unit. This position is also used for monitoring the diffuser (see Chapter 4.4). The scan mirror will be placed in this position during launch.

- *Lamp View*

  This is the position of the wavelength calibration (see Chapter 4.4) with the wavelength calibration lamp.

- *Telescope View*

  In this view, the mirror is positioned such that the mirror surface is normal to the optical axis of the telescope/slit. This position is intended to be used for dark current measurements (on the night side).

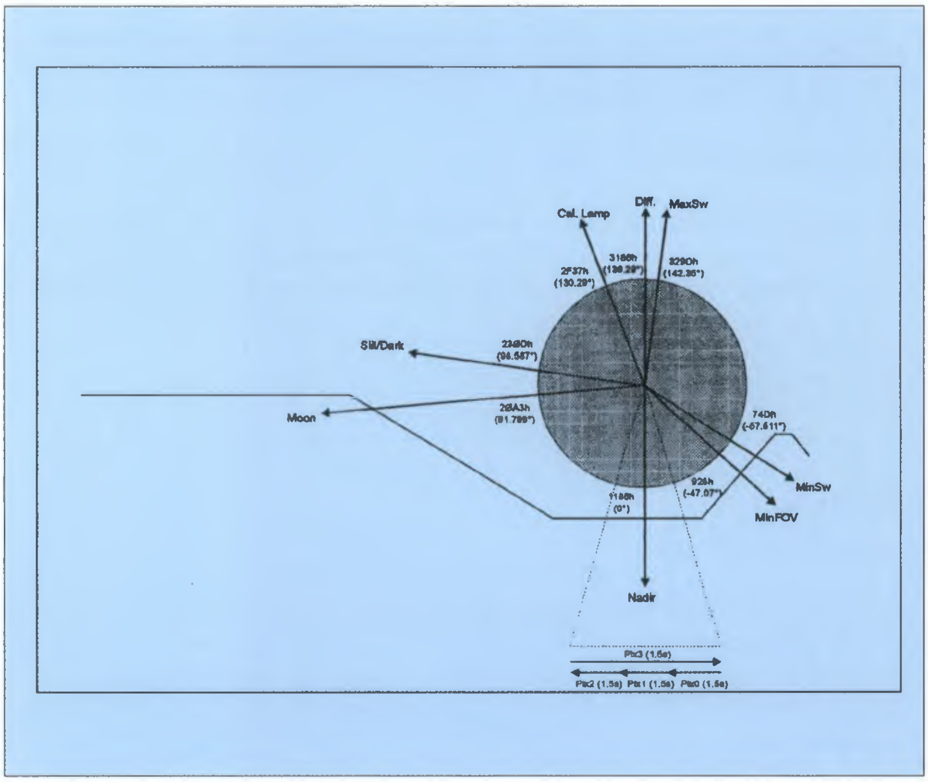
  Figure 4.6-4 shows all the different static pointing positions as well as the software end stops. (Note that the scan mirror surface is **not** on the rotation axis!)

Scanning

The scan unit can be commanded to perform an angular scan around the centre position for the following mechanical angles (optical angles are twice these values):

± 15.488 deg
± 8.495 deg
± 6.470 deg
± 4.362 deg
± 2.196 deg

Figure 4.6-4 Static pointing positions and software end stops of the Scan Unit



Special scans of 0 and ± 60 degrees amplitude can be commanded as well, but are for test purposes only. The centre position does not necessarily mean the zero position; in order to account for the limited alignment accuracy by the much better measurement accuracy of the alignment, a "bias" value can be commanded as the new scan centre position. This feature then also can be used to make non-nadir scans, e.g., around the polar views. The only limitations are the restrictions in the clear field of view.

The SU operation is timed by two hardware signals driven by the DDHU: the SSYNC (Scan Sync) and the MPSTB (Mirror Position Strobe). The SSYNC has a period of 6 sec while the MPSTB has a period of 93.75 millisec (the shortest possible detector integration time; see DDHU in Chapter 4.8).

The SSYNC pulse drives all SU operation and is used to synchronise the SU to the DDHU. 4.5 sec after the last sync pulse, the SU checks whether a new correct command has arrived. If so, the following 1.5 sec are used to drive the mirror to either a fixed position (if a "fixed position" command was received) or to the computed starting position of a scan (if a "scanning" command was received).

At the next SSYNC pulse, the scanner movement will start. The speed profile is shown in Figure 4.6-5. After an initial acceleration period of less than 50 ms, the scanner reaches its constant angular speed, according to the commanded scan. After 4.45 sec, the scanner is decelerated to 0 speed and moved into the opposite direction (the "flyback," at three times the angular speed as for the forward scan). If

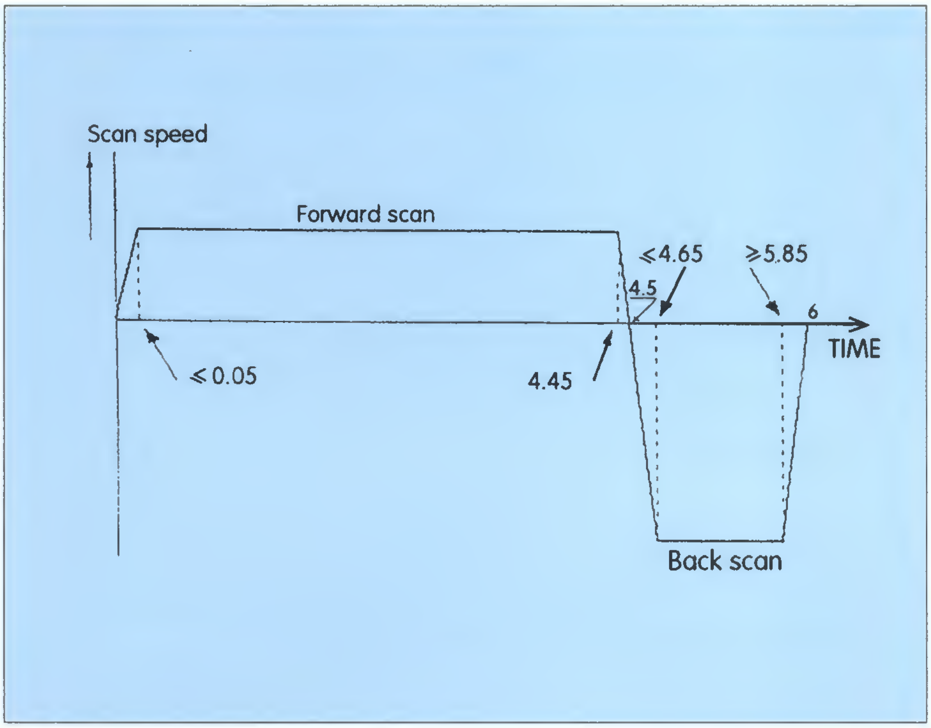


Figure 4.6-5 *Scanner movement speed profile*

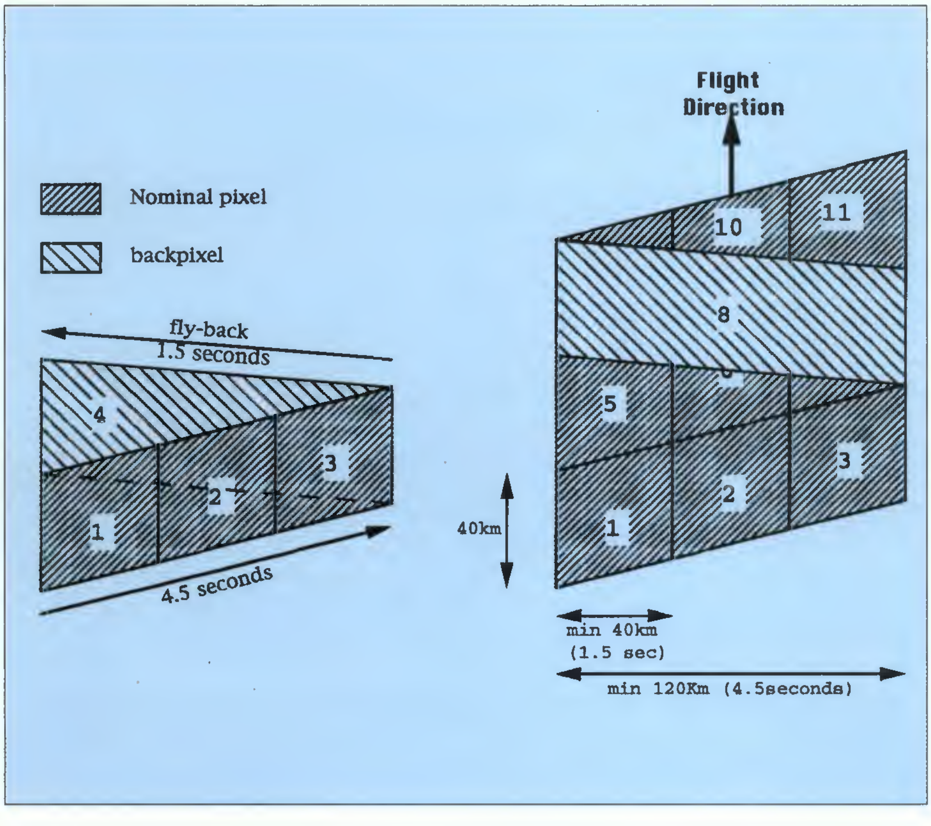


Figure 4.6-6 *Ground coverage within commanded swath widths*

a new mode (new swath or fixed position) is commanded, the starting position for this is achieved within this 1.5 sec period. About 50 ms prior to the end of a 6 sec cycle, the scanner is braked to 0 and awaits the next sync pulse.

As the basic integration time on the detectors is 1.5 sec for the visible channels, this 6 sec period corresponds to four detector integration cycles. With the subsatellite point moving by 40 km in this period, and with the projection of the instantaneous field of view being approximately 40 km by 2 km (along track x across track), a continuous ground coverage within the commanded swath widths is achieved (Figure 4.6-6). The impact of the various swath widths on the global coverage is shown in the coverage plots in the Appendix D.

4.7 Structure and Thermal Control

The structural elements of GOME reside on the **optical bench**, which is supported by four **feet** providing the interface to the satellite. The optics are protected by a **cover**, while the underside of the optical bench is closed by an **EMC shield**. Some **auxiliaries** are accommodated in the structural elements as well: the **harnesses**, the **evacuation system** and a **Quartz Crystal Monitor** (QCM) for contamination monitoring.

For thermal control, the main path is the active **detector cooling chain** which has been partially described in Chapter 4.3. The remaining elements are the flexible connections between FPAs and heat pipes, which end up in the **radiator**. The remainder of the thermal control is via **passive thermal control means**, except for the **OFF/SAFE mode heaters.** **Sensors** are distributed throughout all essential active and passive elements.

Structural Elements

Optical Bench

The optical bench of dimensions 788 x 634 x 79 mm was milled out of a single piece of aluminium alloy. Except for those surfaces used to mount equipment, all surfaces are black anodised.

The top surface carries the optical elements and other items such as electronic boxes directly screwed to the mounting surfaces using threaded holes. All the rim of the top surface is used to attach the cover, except for a protruding part immediately in front of the aperture which carries the alignment cube (see Chapter 2.2).

The bottom surface consists of a outer frame and a web-like structure, with the material in between milled off, which provides the necessary structural stiffness at a moderate weight. The harness and the pipework of the evacuation system are routed through this web, and the off-mode heater mats are attached there. Some holes in the optical bench permit feedthrough of the harness and pipework between the top and bottom sides. The EMC shield is attached at the frame and the centres of the webs.

At the + and - z sides, lids, with central holes in them, protrude. The holes are used to mount the optical bench onto the feet. At the -x side, the radiator is attached via insulating washers.

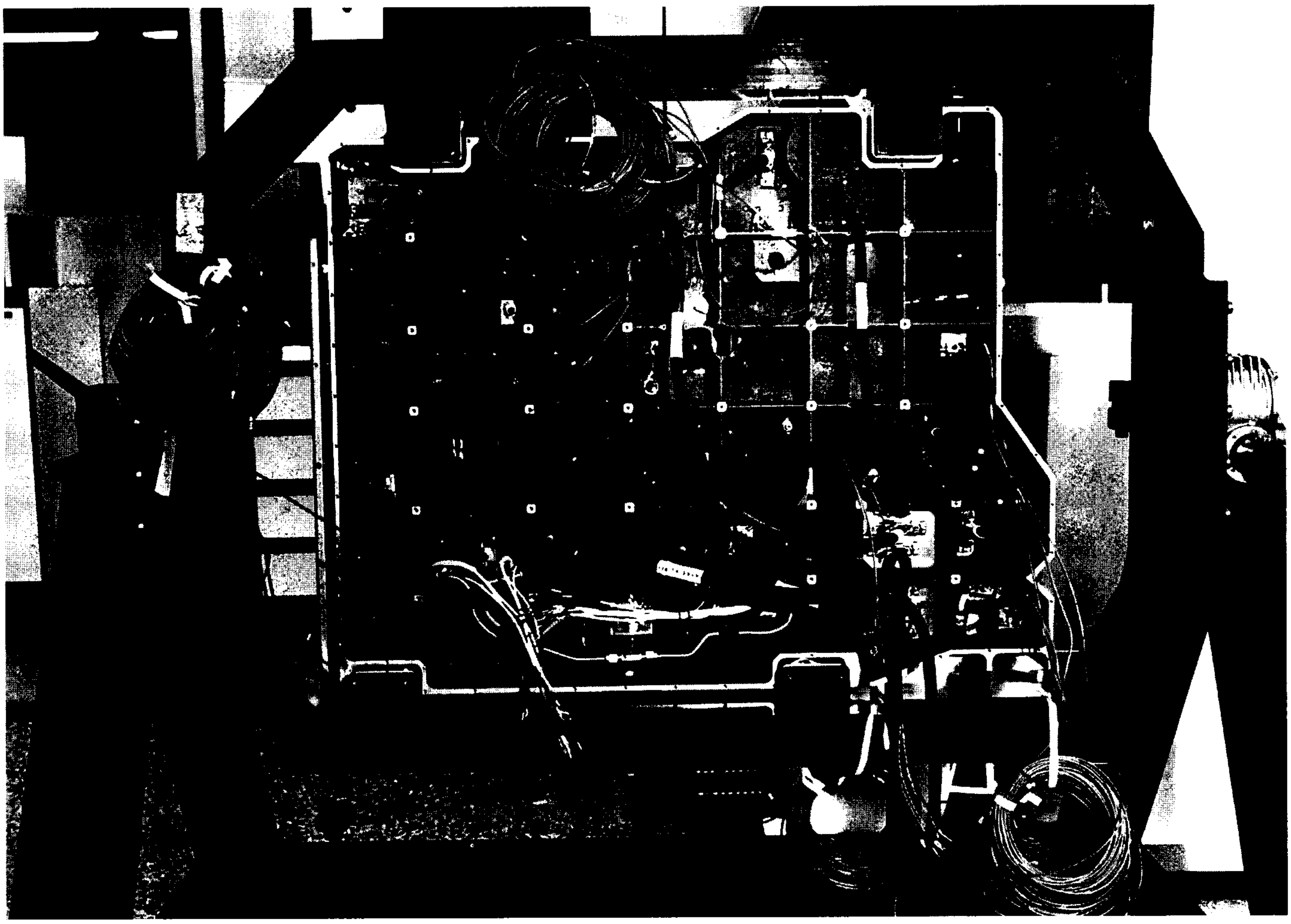


Figure 4.7-1 Bottom view of optical bench during assembly phase

Figure 4.7-1 shows a view to the bottom side of the optical bench during the assembly phase. The top side, with many of the optical elements mounted already, is shown in Figure 4.2-8.

Overall structural stiffness of the optical bench, in the completely assembled state and suspended on the feet, results in a first resonance frequency of about 140 Hz.

Feet

The optical bench is supported by four titanium feet; the feet are locked to the lids in the side of the optical bench frame. Each of the four feet is mounted with four M5 screws and thermal washers to the -y panel of the satellite. The foot next to the main aperture, called the "fixed foot," is 40 mm in circular cross-section and provides a rigid register for the alignment reference. The other three feet are blade-shaped with cross-sections of 40 x 5 mm. The long sides of the blades are oriented normal to the connecting line between the centre of each foot and the centre of the fixed foot. This provides the flexibility to adapt to changing thermal environments without introducing stresses and deformations into the optical path.

Cover

The cover is assembled from milled piece parts of black anodised aluminium. It protects the optics from the environment. Inside the cover are some baffles which form a labyrinth with the baffles mounted on the optical bench. Openings for scanning and sun observation views are provided. During ground handling, the openings are protected by red aperture covers attached to the optical bench cover.

EMC Shield

The EMC shield, made from a simple aluminium sheet, covers the bottom side of the optical bench and forms, together with the optical bench frame and the cover, a nearly closed Faraday cage around the instrument. (Obviously, the openings for the optical apertures are the holes in that Faraday cage.)

Auxiliaries

Internal Harness

All internal harnesses start at the bottom side of the DDHU, where all connectors for internal harnesses are mounted. They are routed through the ribs at the bottom side of the optical bench, and are clamped at these passages. Most of the harnesses can be seen in Figure 4.7-1.

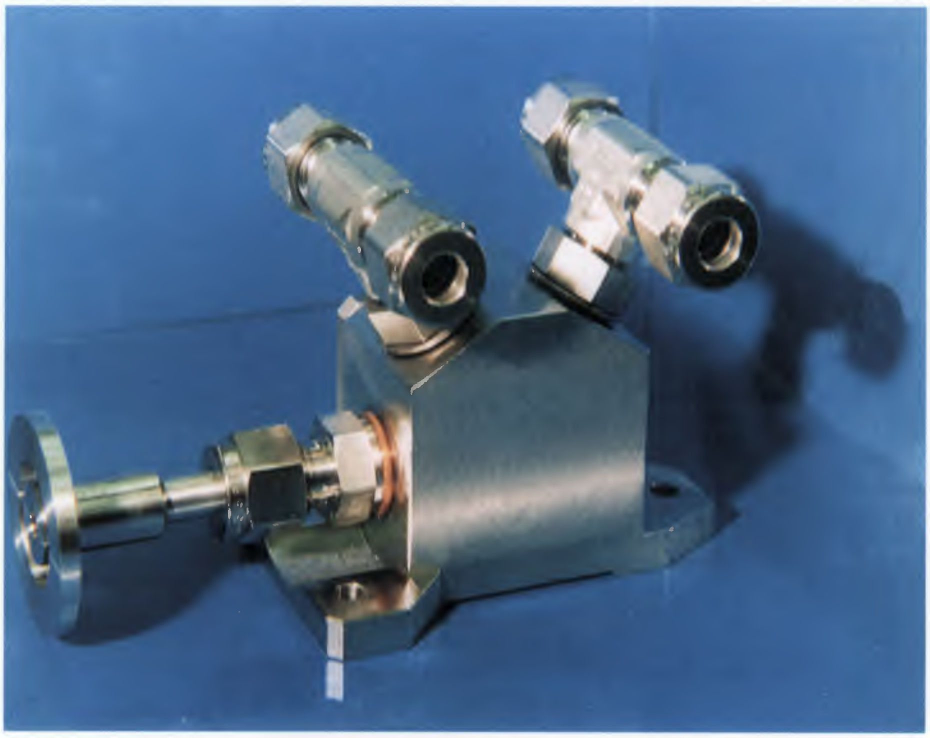
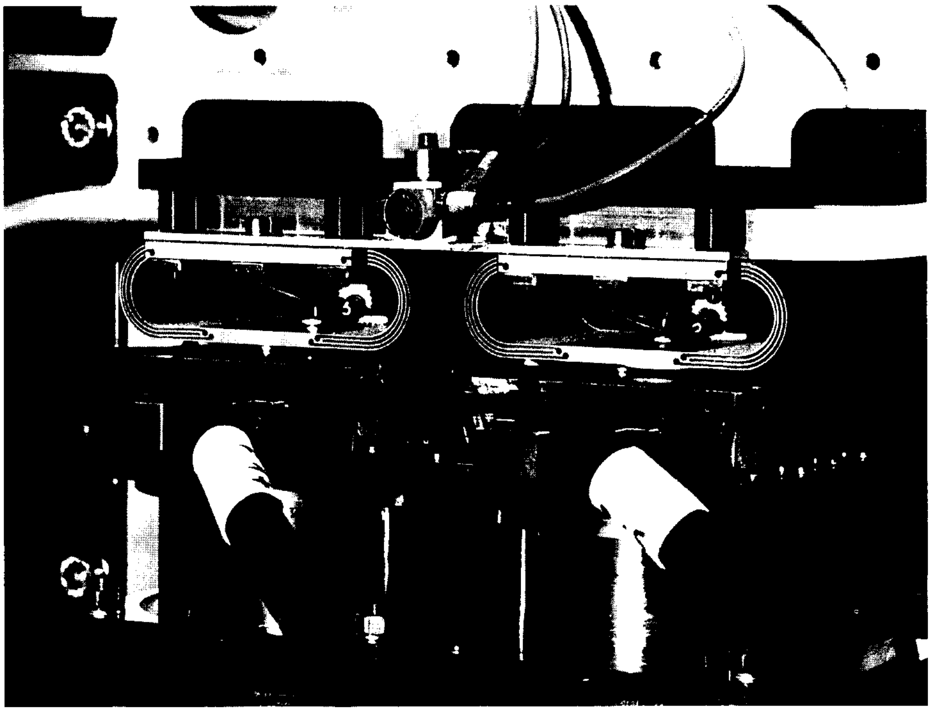


Figure 4.7-2 Evacuation System manifold with the pipe to external flange

Figure 4.7-3 Flexible connection to the heat pipes for detector cooling chain



Evacuation System

During ground operations, the FPAs can be evacuated to prevent freeze-out of water and other condensables on the cooled detectors. Each FPA is equipped with a pipe connection in the vacuum part of the FPA. via flexible metal-bellows tubes, they are connected to a manifold mounted at the bottom side of the optical bench. From this manifold, one rigid connection passes through a hole in the optical bench frame and ends in a conventional NW 10 flange. During ground operations, a valve is mounted to this flange and then interfaces with the vacuum pump system. During periods of transport and storage, dry nitrogen is applied to the FPAs. Figure 4.7-2 shows the manifold with the pipe to the external flange.

During launch preparations, the valve is replaced by a blind flange. This flange is removed at the latest possible point in time to leave the system open to space vacuum after launch. Because of the long diffusion path from the FPA through the flexible tubes, the manifold, and the external pipe, a period of one month is planned to allow for sufficient venting prior to switching the coolers on for the first time.

Quartz Crystal Monitor (QCM)

A quartz crystal monitor (also called microbalance) protrudes from the cover into the space above the optical bench. It monitors contamination of the optics during ground operations.

The external readout electronics have been connected to take recordings at regular intervals. No contamination has been detected. (Next to this internal monitor, external witness plates have been used throughout the AIV Programme.)

Thermal Control

Detector Cooling Chain

The front-end elements of the detector cooling loop have been described already in Chapter 4.3. This includes the Peltier element, brazed to the copper dowel of the pin plate, which reaches through from the vacuum compartment of the FPA to the back end (see Figure 4.3-4).

At the back end, the copper dowel is connected via a flexible connection to the heat pipes. The flexible connection is made from an oval shaped piece of aluminium, wire-eroded at the round parts (Figure 4.7-3). Connections to the copper dowel and the fins of the heat pipes, respectively, are made at the straight parts. In this way, good thermal contact is established, yet enough flexibility is allowed for thermal expansion of the various elements. The bent heat pipes (two off in parallel) have two pairs of fins where they are attached to the external radiator. This radiator looks towards the deep space direction (-x), although with a limited view factor. It is 440 mm high x 485 mm wide. The surface is covered with SSM tape. The radiator is attached to the -x side of the optical bench frame with titanium spacers. (In Figure 4.2-8, one can recognise the heat pipes behind the channel objectives. The radiator is exchanged for a heat exchanger for TV testing.)

Instrument Thermal Control

The remainder of the instrument thermal control is passive. The electronic boxes (DDHU and SUEA) have their own radiative surfaces; non-radiative surfaces are covered with aluminized kapton tape. They are thermally coupled to the optical bench, and prevent its temperature from dropping too low. The optical bench/cover are wrapped in MLI foil, except for the apertures and the space between optical bench/cover and radiator, which are taped with SSM foil. Heat flux to and from the satellite panel is minimized by the isolating washers under the feet and by MLI foil between the panel and EMC shield at the bottom of the optical bench. Figure 2.2-1 shows the fully integrated situation on the satellite.

OFF/SAFE Mode Heaters

When the instrument is "off" (payload off/safe modes), the temperature could drop below the minimum allowed switch-on temperature. The electronic boxes, as well as the optical bench, are therefore equipped with thermostat switched heater mats, which keep temperatures above -25°C.

Flight Predictions for Thermal Control

On the basis of test results obtained with the BBM at instrument and payload level TB/TV tests, and FM at instrument level, the temperature distributions as a function of operational mode have been modelled. The results of this flight prediction are reported in Table 4.7-4.

Mean optical bench temperature:	
hot operational case	24°C
cold operational case	6°C
Radiator temperature:	
hot case	- 3°C
cold case	- 24°C
Peltier hot side temperature (cold side at - 38°C):	
hot case	11 to 13°C
cold case	- 15 to - 13°C
Orbital fluctuations of O/B temp.	< ± 1°C
Maximum temperature gradient along O/B:	
hot case	0.28°C/m
cold case	0.13°C/m
Hot case, with Calibration Lamp on	0.90°C/m
Temperature increase at predisperser prism:	
after 1 orbit of lamp operation	0.43°C
after 3 orbits of lamp operation	1.8°C
Maximum heat flow between GOME and mounting panel	< 3 W
Heater power demand:	
off mode	13 W
safe mode	23 W

Table 4.7-4 Thermal Control Performance Predictions

4.8 DDHU and DEU

As outlined in the introduction (Chapter 1.2), at the beginning of the GOME project it was decided not to provide GOME with its own Instrument Control Unit (ICU) but instead provide this service through the Digital Electronics Unit (DEU) of the ATSR instrument. The ATSR (apart from the DEU being the common electronics) consists of two sub-instruments: the Infrared Radiometer (IRR) and the Microwave Radiometer (MWR). As this single non-redundant electronics unit would control three instruments (including GOME), it was decided to employ a second, identical DEU and a "DEU switching unit" to provide the cross-strapping between the DEUs and the instruments (IRR, MWR, and GOME). Figure 4.8-1 shows a block diagram of the ATSR/GOME assembly and its electrical interfaces with the satellite subsystems.

Services provided to GOME by the DEUs are described briefly in the next sub-section, followed by a design description of the DSU. The design, interfaces with GOME subsystems, and functions of the DDHU (GOME's main electronics) are then described.

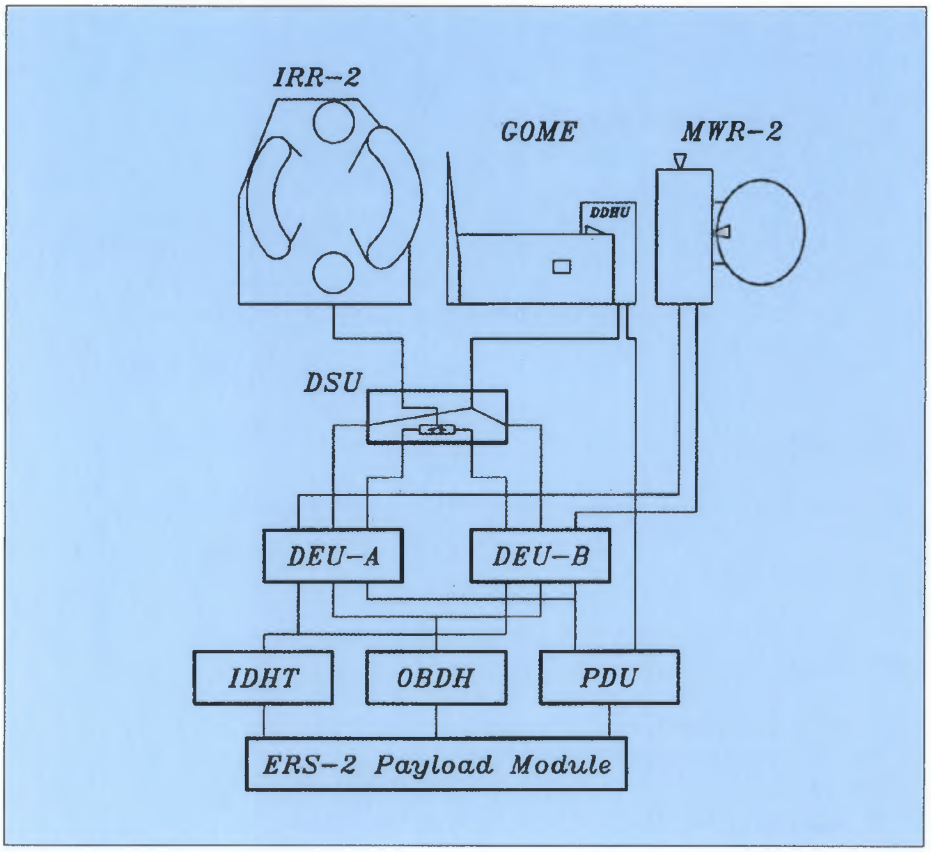


Figure 4.8-1 DEU/DSU/IRR/MWR/GOME block diagram

4.8.1 DEUs and DSU

The DEUs provide the following services to GOME: commanding, telemetry acquisition, science data acquisition, timing and surveillance. These services are described in detail in the following paragraphs:

Commanding

The DEUs interface with the ERS On-Board Computer (OBC) via the On-Board Data Handling (OBDH) bus and are the addressees for GOME-related, uplinked macrocommands (MCMDs). There are five GOME related MCMDs:

GOME on: Powers GOME by activating a relay in the DDHU acting on the prime power bus coming from the Power Distribution Unit (PDU)

GOME off: De-powers GOME.

GOME Parameter: The values in the parameter, converted by the DEU into a serial bit stream to the DDHU, contain the settings of all subsystems and parameters. When forwarded to the DDHU, the ICU time is appended. (For details of the settings, see Chapter 7.1).

GOME Timeline No. (1, 2 or 3) Load:	Loads a timeline addressed to GOME into one of the three DEU memory are as reserved for this. A timeline consists of up to 30 parameters (as contained in the "GOME Parameter" MCMD) plus a delay value for each parameter.
GOME Timeline No. (1, 2 or 3) Activate:	Starts the execution of the respective timelines. According to the specified delay with respect to the starting time of the timeline, command bit streams are sent to the DDHU.

One timeline can, in principle, run successively for up to 16 times; the number of repetitions is contained in the "Activate" format.

The hardware interface consists of differential signal lines for command, strobe and clock.

Telemetry

The DEUs acquire housekeeping telemetry from the DDHU and send it to the ground via the OBDH/OBC and the S-band link. The contents of this housekeeping information is the same as is put into the first frame of the science packet (see next paragraph). Because of the constraints of the existing system, GOME housekeeping data are transmitted for 16 sec, alternating with ATSR housekeeping information every 32 sec. (This limits the visibility of GOME behaviour somewhat for the operations people.) The hardware interface consists of four differential signal lines: telemetry data, sample (to initiate the word transfer), clock, and request (to initiate a "frozen" housekeeping set to be transmitted).

Science Data Acquisition

The DEUs acquire the GOME science packets, which are transferred to ground via the IDHT and X-Band interface. A science packet, comprised of 20 frames with 200 words each, is produced nominally by the GOME every 1.5 seconds. Since the generation interval of the ATSR-2 DEU varies as a function of the instrument mode (150 milliseconds if the ATSR IRR is ON, 151 milliseconds if the IRR is OFF), the GOME is able to discard the last frame of its science packet if the DEU is too slow to acquire the data with respect to the 1.5 second rate. When the IRR is ON, all packets will contain 20 frames; when the IRR is OFF (non-nominal case), two frames will be discarded every seven science packets. (Packets will be shortened to 19 or 18 frames by the DDHU.)

Timing

The DEUs pass on the OBDH clock signal, its rate divided to 256 Hz, to the DDHU. From this clock signal and the ICU time appended to the command word, the datation of the science data is derived.

Hardware implementation is via a differential line carrying the clock.

Surveillance

Limited surveillance (and reporting of detected anomalies) is done by the DEUs. No autonomous re-configuration of GOME will result from this surveillance.

DSU

The DSU is the unit in which the signal and power lines from the two DEUs (A and B) are merged to the non-redundant sub-instruments (IRR, MWR, and GOME). Signal lines are passively spliced (two drivers into one receiver, and two receivers for one driver). The selection of which DEU to activate is by ground command to the ICU power relay in the payload Power Distribution Unit.

4.8.2 Detection and Data Handling Unit (DDHU)

All the GOME electrical interfaces to the ERS-2 payload are located in this unit. Moreover, it receives the GOME commands, controls all the other GOME subsystems according to those commands, and collects the relevant scientific and housekeeping telemetry. As such, it is the most important unit from an operations point of view.

The DDHU is located in the +Y/+Z corner of the optical bench. It is composed of eight electronics boards (power supply module, pixel readout logic, power control and service block, analog processor module, GOME microprocessor board, remote telemetry module, Peltier control module, and mother board), which are described in the following paragraphs. These boards are inserted into the DDHU as shown in Figure 4.8.2-1; Figure 4.8.2-2 shows the box open.

Power Supply Module

The main function of this board is to generate all the secondary supplies needed by the GOME subsystems, including the DDHU itself but excluding the calibration

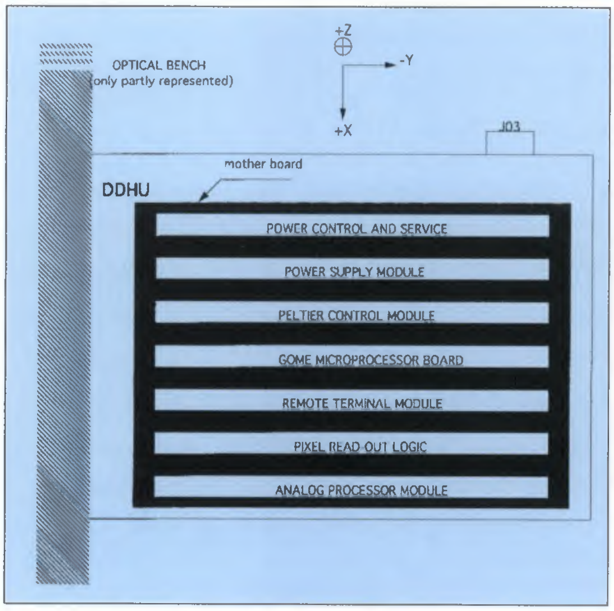


Figure 4.8.2-1 Board configuration in the DDHU

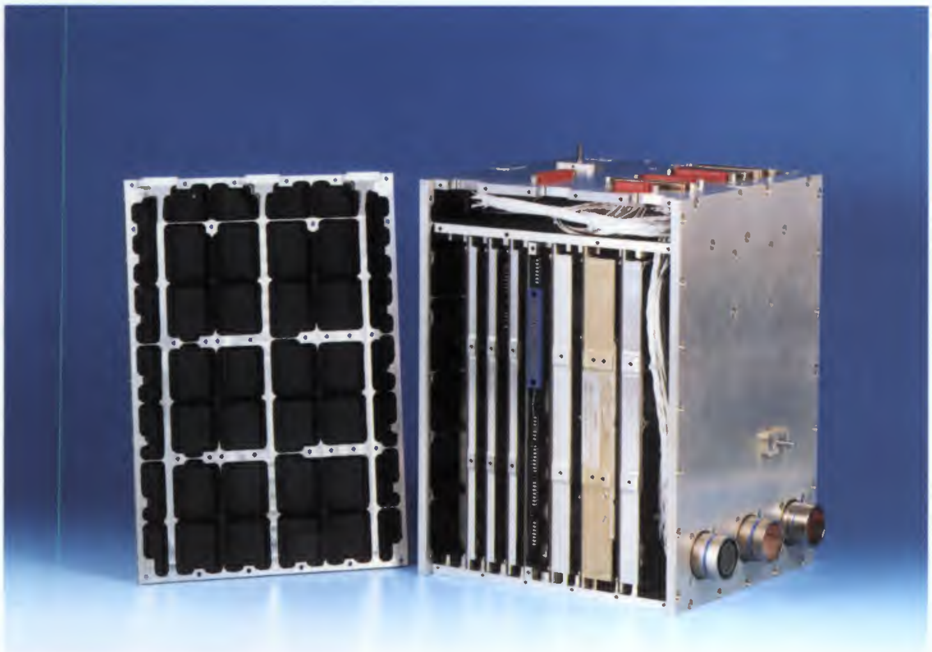


Figure 4.8.2-2 DDHU box open showing electronics boards

unit lamp (see Calibration Unit, Chapter 4.4). This is achieved using a DC/DC converter which converts the GOME NOMINAL POWER bus from the PL-PDU (28 V unregulated) to the required secondary levels. The switching frequency (65.5 kHz) of the DC/DC converter and its phase are slaved to the GOME master clock in order to minimise internal GOME EMC problems. The same 65.5 kHz signal is distributed as well to the CU power supply for the same reason.

The secondary supplies are isolated with respect to the primary power bus, which may vary from 22 Volts to 37 Volts, without detrimental effect on GOME operations. The secondary outputs are:

- +5 Volts: digital supply used for the DDHU itself and electrical interface circuitry.
- +28 Volts: supply used for the detector thermal control and the cover emergency mode.
- +/-12 Volts: used directly for the scan mirror unit and indirectly with +/-9 Volts series regulator to the PU and the analog circuitry in APM and FPA. It also powers a current source which is used for opening/closing the CU shutter in nominal mode.
- +8 Volts analog: precise supply used by the APM and the RTM. It also provides the current sources which supply the LEDs.
- -5 Volts analog: used by the RTM board.

The power supply board temperature is measured by the DDHU itself and by the PL-PDU.

Pixel Readout Logic

The Pixel Readout Logic (PRL) board is composed of the following blocks:

- Time base and synchronisation: generation and the synchronisation for the entire DDHU and the GOME subsystem are performed by the clocks.
- ADC logic: the control signals for APM.
- Address generation: the address for the FPA pixels.
- OBC timer I/F: the interface to acquire and count the 256 Hz signal derived from the OBDH clock by the ATSR DEU.
- Anti-latch-up circuitry: the anti-latch-up protection for APM.
- Bus I/F: the bus interface to/from the DDHU system bus.

The Pixel Readout Logic board generates the address and the strobe to each pixel of the four FPA detectors. Each detector is made of an array of 1024 pixels. The pixels are addressed sequentially, one pixel every 91.55 μs; if the specified integration time (IT) for that pixel has elapsed, a strobe signal is generated to the array and a pulse, proportional to the quantity of light integrated on that pixel, is presented to the video input of the APM board for conversion.

Each readout operation resets the corresponding array pixel, hence the integration time is the time distance between two consecutive strobe pulses addressed to the same pixel. The nominal pixel readout time is 91.55 μs, leading to a minimum IT of 93.75 ms (1024 * 91.55 μs). The duration of a "ground pixel" is nominally 1.5 seconds in the visible and corresponds to 16 minimum ITs.

No more than one useful readout, performed by DMA transfer from APM's ADC to memory, is made every 1.5 seconds. If the selected IT is shorter than 1.5 seconds, software commands the PRL to insert a proper number of 'dummy readouts' according to the integration time selected. Such 'dummy readouts' always correspond to an IT of 93.75 ms duration.

For integration times longer than 1.5 seconds, the PRL presents an invalid pattern ('FFFFHex') meaning that the integration time is not yet completed within the present 1.5 second interval. The pixel readout is synchronised with the scan mirror movement whose period is 6 seconds.

Another DMA data transfer relates to the PRL. It consists of programming the PRL for every pixel of each array to indicate whether its nominal IT is complete and initiates a readout. A PRT table is computed by the DDHU processor for every 93.75 ms period for that purpose.

To summarise, there are two types of DMA transfers associated with that board:

- one 'write' type which transfers one line of PRT to control the integration time and to select if the data or dummy must be taken away from the APM's ADC;
- one 'read' type which transfers data converted from the APM's ADCs to memory.

It must be noted that the PRL has total hardware control over the APM board (ADC conversion, transfer, etc.).

The PRL temperature is measured by the DDHU and transmitted to the ground.

Power Control and Service Block

The main purpose of the PCS (Power Control and Service) board is to switch and control various power lines:

- Main power line
- Calibration Unit line
- Mirror heater line
- Cover motor line

Furthermore, it furnishes other services:

- Power supply to external sensors
- Current regulation for calibration LEDs
- RS232 interface

The main power line is switched on and off by two separate lines received from the DEU. In addition, the PCS receives a separate Switch Off Line (SOL) from the payload power distribution unit to switch off the unit in case of an emergency.

The calibration unit is powered directly from the primary 28 Volts which is controlled by means of a latching relay. (Refer to the Calibration Unit, Chapter 4.4.) Two other circuits control power to the mirror heater and to the cover motor, and send the appropriate supply polarity for movements. The status of the cover reeds relays is acquired on that board as well and put into an I/O register which can be accessed by the DDHU software.

A power regulator is included on that board to supply the optical sensors and related electronics. The constant current sources for the calibration LEDs are mounted on this board as well.

The RS232 interface provided a convenient way to load software and test the GOME instrument on the ground. This interface is disabled during flight.

Analog Processor Module

The main function of the board is to filter and digitally convert the voltage coming from the diodes of the FPA arrays.

The voltage from the diodes is filtered through a Double Differentiating, Double Integrating (DDDI) circuit (analog filter) and then applied to the ADC. The four converters work in parallel and produce four 16-bit words which are read by the central processor by means of a DMA technique (refer back to the PRL section). These converters provide an on-chip calibration function which can be run consecutively or interleaved. A continuous calibration is initiated at power-up, or after a latch-up or by command, and takes ~400 ms to complete. At the end of this calibration, the converter is controlled by the DDHU software to enter an interleaved calibration which runs forever and completes every ~5 seconds. The latter mode of calibration is totally transparent to the DDHU processor.

Polarisation and motor current acquisition is also performed on that board. The three PU detectors (see Chapter 4.5) and the IMOT signals are acquired through a multiplexer by an ADC that stores the converted data in four registers. The registers are downloaded on interrupt call by the digital processor module. The four signals are read 16 times and averaged by software over the 93.75 ms period. It is possible to disable this averaging function.

The same board contains a precise 5-Volt regulator for the ADC and anti-latch-up circuitry which switches off the complete APM analog circuit if the current is greater than 100 milliamperes. The enabling of the supply is performed under software control. Four temperature sensors are mounted on this board to allow precise monitoring of the analog chain temperature.

GOME Microprocessor Circuit (GMC) Board

The GMC consists of a PCB with two hybrid circuits. One hybrid contains the microprocessor, the PROM, and the most important I/O circuits and glue logic, while the other hybrid contains the RAM and EEPROM memory. The remaining logic associated with the use of a processor is installed on the PCB itself.

Main processor configuration:

• processor type:	80C86
• crystal clock:	14.680064 MHz (Master Clock)
• processor clock derived from master clock:	4.893 MHz
• PROM:	4 Kbytes
• EEPROM:	32 Kbytes
• RAM:	96 Kbytes
• RS232 I/F to SU:	80C52
• RS232 I/F to EGSE:	82C52
• DMA controller:	82C37
• Master interrupt controller:	82C59
• Slave interrupt controller:	82C59
• Programmable interval timer:	82C54

From an operations point of view, the processor board is detailed in the functional chapters of this document.

Remote Telemetry Module (RTM)

The RTM implements most of the hardware interfaces between GOME and the ATSR DEU, as well as the acquisition of auxiliary analog telemetry from the various GOME subsystems. The term 'auxiliary' relates to the fact that the critical science analog acquisition is performed by the APM described above.

The 'DEU interface' functions are:

- reception of the differential signals from the DEU
- conversion of differential signals to single-ended signals
- serial to parallel conversion to transfer relevant commands to GMC
- parallel to serial conversion of HK and science telemetry from GMC
- transfer of these telemetry data to the DEU via differential interfaces
- control of DMA channel to transfer science data from GMC to RTM
- control of DMA channel to transfer HK data from GMC to RTM

- temporary storage of command words from DEU into FIFO
- generation of hardware interrupt to GMC when a new command is received

The analog acquisition functions are:

- acquisition of all GOME temperature sensors
- acquisition of the CU voltage and current
- acquisition of analog chain offsets
- selection by software of the conversion gain
  to maximise the span of the ADC

The baseline is that differential signals are measured with low gain, and single-ended signals are measured with high gain.

The various channels and measurement options are selected with a software-driven multiplexer. Note that the scan mirror temperature signal is monitored continuously by the hardware of the RTM to provide feedback for the scan mirror heater mode.

Peltier Control Module

The function of this board is to stabilise the temperature of the four FPA detectors individually. Cooling the detectors reduces their dark current which is a source of noise; warming of the detectors could introduce attenuation effects due to contamination or radiation. The board has been designed to be software controlled to allow more flexibility during the design and test phases. Moreover, this flexibility will permit changes to some parameters of the thermal control loop, in case the GOME thermal system degrades. The module is composed of the following components:

- Four step-down converters to partition the incoming 28 Volts secondary supply from the power supply module into a 0 to 5 Volts supply to the Peltier element after passive filtering.
- Relays to select polarity of the voltage to the Peltier and implement cooling or warming of the detectors.
- Four software-loaded registers to control the step-down converters and relays.

Each bit of the step-down converter control register corresponds to ~125 mV output to the Peltier coolers. The maximum voltage is limited by software to 4.625 Volts. A built-in overvoltage limiter will prevent the Peltier output from rising beyond 5.5 V. Moreover, a current limiter will trigger and turn off the Peltier output if any Peltier current exceeds 1.5 A.

One temperature sensor is mounted on the board; its output is transmitted to the ground.

5. Instrument Performance

GOME FM underwent a series of test and performance evaluation activities. The major test campaigns were:

- Functional and Performance test in clean room at Galileo
- Vibration test at Dornier
- EMC test at Dornier
- Payload level test at ESTEC
- TV test at Galileo
- Calibration and characterisation at TPD.

The summary of the performance evaluation results presented in this chapter focus mainly on characterisation results, whereas the calibration results are described in the next chapter.

The performance evaluation results of GOME described here report the in-orbit situation, which means measurements have been performed in vacuum and at about 20°C optical bench temperature. The temperature reference point is the predisperser prism. Parameters such as instantaneous Field of View and pupil area, which are by design not affected by these assumptions, are measured in ambient air and at room temperature.

5.1 Instantaneous Field of View

The instantaneous Field of View is defined as

- along track: the projection of the length of the detector pixel through the telescope, designed for 2.87 deg.
- across track: the projection of the width of the entrance slit through the telescope, designed for 0.14 deg.

The actual figures for Field of View as measured are as per Table 5.1-1:

Channel	along track (deg)	across track (deg)
1	2.72 - 2.74	0.139
2	2.57 - 2.61	0.139
3	2.63 - 2.81	0.139
4	2.74 - 2.77	0.139

*Table 5.1-1 Measurements of Instantaneous Field of View**

The PMD channels have the following characteristics:

PMD channel 1: 2.59 deg
PMD channel 2: 2.59 deg
PMD channel 3: 2.59 deg.

These channels overlap more than 97% with the main channels.

* The different values in the along-track direction correspond to the wavelength extremes of each channel.

5.2 Pupil Area

The pupil area is defined by diaphragms and by the values of the optical components in the instrument, and is hence channel dependent. The principal diaphragm, having a circular shape of 25 mm diameter, is located at the predisperser prism. For channels 3 and 4, an elliptical diaphragm in their common parallel light path, with axes length of 24.1 mm by 17 mm, defines their pupil areas.

An asymmetric diaphragm at the front of the objective of channel 2 reduces the relative pupil area linearly from 1 at 320 nm to 0.6 at 400 nm.

The overall figures for the size of the entrance pupil for the different channels are:

Channel 1 : 0.980 cm^2
Channel 2 : 0.980 cm^2 (at 320 nm)
Channel 3 : 0.215 cm^2
Channel 4 : 0.215 cm^2

5.3 Spectral Coverage and Resolution

The spectral coverage of the GOME FM is defined by the optical layout and the mechanical adjustment of the four detectors in the focal planes. The results, presented in Table 5.3-1, are deduced from TV test data and are representative for vacuum conditions at about 20°C.

Band / Parameter	1A	1B	2	3	4
Spectral Coverage [nm]	240 -307	307 - 316	311 - 405	405 - 611	595 - 793
Spectral Resolution [nm]	0.20	0.20	0.17	0.29	0.33

Table 5.3-1 Spectral coverage and resolution

The channel separation at 50% of the overlap regions is as follows:

Channel 1 - 2 313.4 nm
Channel 2 - 3 not useful
Channel 3 - 4 606.50 nm

5.4 Spectral Stability

Spectral stability was assessed during the instrument level TV test. During the execution of the test, GOME had been temperature cycled between -20°C and + 40°C. Each measurement was performed after having reached a steady-state situation. The values represent the average shift in pixel of the analysed spectral lines. The ambient pressure situation is given for information. The temperature is referenced to the predisperser prism.

Pressure	Temperature	Shift ch1	Shift ch 2	Shift ch 3	Shift ch 4	
Ambient	20.2°C	-1.46	-1.85	-1.25	-1.87	
Vacuum	22.7°C	0	0	0	0	Reference
Vacuum	-13.8°C	0.556	0.197	1.004	0.202	
Vacuum	0.45°C	0.409	0.033	0.648	0.112	
Vacuum	19.7°C	0.215	-0.014	0.061	0.056	
Vacuum	39.4°C	0.011	-0.073	0.067	0.008	

Table 5.4-1 Spectral shifts as a function of temperature

The resulting temperature shift per degree C is given below. As the fluctuation of the temperature around an orbit is expected to be about 1.6°C, the third column gives the expected wavelength stability per orbit.

channel 1	0.023 pixel/deg	0.037 pixel/orbit
channel 2	0.015 pixel/deg	0.024 pixel/orbit
channel 3	0.028 pixel/deg	0.045 pixel/orbit
channel 4	0.021 pixel/deg	0.034 pixel/orbit

The particular set-up in the instrument TV test gave a somewhat optimistic picture, because it minimised gradients in the optical bench and their variations. In reality, the spectral shifts are expected to be larger by a factor of two than those reported above. As an order of magnitude, this has been confirmed with the BBM in the payload thermal balance test.

5.5 Optical Efficiency

Optical efficiency was measured at the component level and then compiled for the end-to-end assessment. The individual measurements were done by Galileo, Balzers and Carl Zeiss.

The definition of the polarisation direction of GOME is made with reference to the orientation of the four gratings, the main polarisation-sensitive elements. Parallel means parallel to the grating grooves and therefore parallel to the entrance slit. This is also the signal measured with the polarisation measurement device (PMD). In the literature, polarisation directions are sometimes referenced to the incidence plane of the incoming radiation. In this case, the GOME definition of p and s polarisation must be switched.

The overall results of optical efficiency are:

Channel 1

Wavelength (nm)		239			267			300	
Polarisation	s	p	avg	s	p	avg	s	p	avg
Optical Efficiency	0.14	0.22	0.18	0.16	0.28	0.23	0.13	0.35	0.24

Channel 2

Wavelength (nm)		320			360			400	
Polarisation	s	p	avg	s	p	avg	s	p	avg
Optical Efficiency	0.15	0.29	0.22	0.10	0.23	0.17	0.08	0.17	0.12

Channel 3

Wavelength (nm)		400			502			605	
Polarisation	s	p	avg	s	p	avg	s	p	avg
Optical Efficiency	0.14	0.15	0.14	0.18	0.24	0.21	0.08	0.07	0.08

Channel 4

Wavelength (nm)		600			690			790	
Polarisation	s	p	avg	s	p	avg	s	p	avg
Optical Efficiency	0.01	0.03	0.02	0.10	0.08	0.09	0.06	0.06	0.06

Table 5.5-1 : Optical efficiency of polarised channels

Table 5.5-1 Optical efficiency of GOME channels for p, s polarisation and as an average (i.e., for unpolarised light).

5.6 Stray Light Characterisation

Stray light in GOME consists of uniformly distributed stray light, plus ghosts, and inter-channel stray light (stray light as a result of flux from the other channels), but is mainly intra-channel stray light (stray light within one channel).

Ghost lines are a more or less focused image of a spectral range on another part of the channel. These ghosts are created by a specular reflection of light impinging on the detector, which is reflected back in zeroth order of the grating or from the surfaces of the lenses closest to the detectors.

The design goal for stray light reduction was "1% of the expected signal flux." For spectral regions with a change in signal by many decades, such as in channel 1 and partly in channel 2, this requirement has to be folded with the expected signal flux for the in-orbit situation. This results in a "1% level of the expected signal per detector element." As a result, the acceptable stray light levels are:

Channel 1:	0.0085% at 240 nm 0.28% at 290 nm
Channel 2:	0.11% at 310 nm 0.99 % at 350 nm
Channels 3 and 4:	1% at all wavelengths

The actual figures for the uniform stray light level are:

Channel 1:	not measurable
Channel 2:	0.3 %
Channel 3:	0.3 %
Channel 4:	0.2 %

Ghost characterisation was done and is reported in the following table. The defocusing information is the ratio of the full width at half maximum of the ghost line to the parent line. The illumination wavelength is the centre wavelength of the interference filter used.

	Illumination Wavelength	Pixel of Symmetry	Defocusing Ratio	Energy Ratio
Channel 1		-	-	-
Channel 2	320 nm	530	0.6	0.1%
Channel 2	380 nm	547	0.8	0.05%
Channel 3	450 nm	480	1.0	0.2 %
Channel 3	550 nm	478	1.2	0.1 %
Channel 4	650 nm	547	1.1	0.02 %
Channel 4	750 nm	550	1.4	0.05%

Table 5.6-1 Ghost (stray light) characterisations

The levels of inter-channel stray light are so small that they are not of importance.

5.7 Electro-Optical Performance

5.7.1 Noise of Electrical Chain

The noise of the electrical chain was assessed at several points in the test flow of GOME FM. In most cases, noise was assessed for the following conditions:

- detector cooled to 235 K
- integration times of 93.75 msec and 1.5 sec
- noise defined as standard deviation of a set of 256 measurements

The mean noise figure is 2000 electrons.

The noise in electrons can be converted to binary units (BU) by using the relation:

903 electrons equals 1 BU.

5.7.2 Signal Chain Offset

The offset of the signal chain is:

Channel 1	148 BU
Channel 2	143 BU
Channel 3	144 BU
Channel 4	140 BU

5.7.3 Saturation Level

The individual detector arrays used in channels 1 to 4 all have slightly different saturation values, which are defined by the maximum capacity of the p-n junction in the individual pixels. The maximum signal outputs at saturation are:

Channel 1	55488 BU (9.0 pC)
Channel 2	57961 BU (9.1 pC)
Channel 3	53440 BU (8.9 pC)
Channel 4	59119 BU (9.5 pC)

5.7.4 Dark Current

Dark current behaviour of the four Reticon detector arrays has been measured at 235 K.

Channel 1	0.29 fA
Channel 2	0.27 fA
Channel 3	0.26 fA
Channel 4	0.23 fA

5.7.5 Signal-to-Noise Ratios

Signal-to-noise ratios were verified by analysis (related photon noise and the noise of the electronic chain) for the nominal fluxes specified in the following table:

Channel	Integration Time	Wavelength	Required S/N	Measured S/N
1	30 s	240	13	10
1	30 s	268	60	54
1	30 s	290	400	434
1	30 s	310	4000	6325
2	1.5 s	312	600	849
2	1.5 s	320	1600	3609
2	1.5 s	350	2000	4682
2	1.5 s	400	4000	5134
3	1.5 s	460	4000	3967
3	1.5 s	590	4000	4251
4	1.5 s	600	4000	1925
4	1.5 s	670	4000	4214
4	1.5 s	790	4000	3139

Table 5.7-1 Signal-to-noise ratios

5.8 Slit Function

The slit function of GOME was assessed by analysing the measurements of the internal wavelength calibration lamp at several steps in the environmental testing of GOME FM. A comparison of these slit functions with slit functions derived from external light sources (Hg lamp) does not show large discrepancies, except for channel 2. The slit functions derived vary with:

- pressure (ambient or vacuum)
- temperature (-15° C to +40° C)
- position on the detector array.

The complete set of slit functions is available as part of the key calibration data.
The slit functions of GOME for the vacuum conditions at 20 C can be described by the formula:

$$f(x) = a_1^2/[(x-x_0)^4 + a_0^2]$$

with x_0 being the centre of line position and a_1 and a_0 as follows:

Channel	[illegible]	[illegible]
[illegible]	0.8182	0.8196
2	0.6568	0.6568
3	0.7679	0.7675
4	0.7381	0.7377

Note: The application of the slit function is for the convolution of high resolution absorption cross-section measurements from literature references to the GOME resolution.

5.9 Polarisation Monitoring Device (PMD)

5.9.1 Spectral Coverage of PMD

The PMD spectral coverage and the signal-to-noise ratio were analysed in vacuum and are reported below.

The channel separation of the PMD is realized by imaging a polarised, low-dispersion spectrum, generated by the predisperser prism onto the PMD detectors. The three detectors for the UV, visible and red spectral bands are different in size to compensate for non-linear dispersion. The PMD 3 for the infrared is only 0.36 mm broad, but covers 200 nm. The difference between the refractive index of the predisperser prism (fused silica) in air and vacuum leads to a shift in wavelength coverage. As a consequence, the fixed detectors monitor slightly different wavelength bands in vacuum than in air. The wavelength bands covered in vacuum were assessed as part of the TV test:

Channel	Required Coverage	Measured Coverage
1 (UV)	300 - 400 nm	295 - 397 nm
2 (Visible)	400 - 600 nm	397 - 580 nm
3 (Red)	600 - 800 nm	580 - 745 nm

5.9.2 Stray Light in the PMD

The PMD sensors are sensitive to long-wavelength stray light, which illuminates PMDs 1 and 2. The amount of light is difficult to assess because it cannot be measured at the same time with the Reticon detectors. A first assessment showed that, with a laboratory light source, 4% of the PMD 1 signal came from wavelengths 700 - 1200 nm and less than 1% of the PMD 2 signal.

5.9.3 Signal-to-Noise of the PMD

The signal-to-noise ratios of the PMD were evaluated by analysis of the noise data taken during the TV test and by evaluating the expected signal output.

The expected signal output is about 18000 BU. The rms noise levels are very small as a consequence of the averaging process (16 samples per 93.75 msec are averaged). The noise level is below 1 BU. Taking into account the photon noise, the signal-to-noise values are:

PMD 1	22500
PMD 2	90000
PMD 3	90000

5.9.4 Temperature Drift of the PMD

The temperature drift of the PMDs was assessed during the TV test and is quantified as follows:

PMD 1	0.23%/deg C
PMD 2	0.27%/deg C
PMD 3	0.36%/deg C

5.9.5 Instrument Performance during TB/TV Test

During the satellite TB/TV test performed in September 1993, GOME FM was not available and therefore the BBM replaced the GOME FM during this test. Nevertheless, due to the very similar design of GOME BBM and FM, the results can be used for a performance assessment.

The following results are based on the outcome of this test:

- orbital variation of the reference temperature sensor on the optical bench is +/- 0.8 K.
- average temperature of the optical bench is typically 7-10 K lower than the predicted values. This is mainly caused by a stronger coupling between the optical bench and the local radiators of the electronic unit and the scan mirror electronic unit. The average values of the final flight predictions are 2°C in cold operation (beginning-of-life, summer solstice) and about 21°C in hot operation (end-of-life, winter solstice).
- temperature differences on the optical bench are less than 2.5 K.
- temperature increase at the optical bench (reference point) after three orbits of operation of the calibration lamp is 2.3 K (after one orbit, 0.6 K).
- stray light can enter the instrument via the scan unit.

The last point has been overcome by using an improved design of the baffling system of GOME for the FM.

The spectral shift of lines during one orbit for the four different channels has been assessed by TPD. The following values are reported:

	Maximum drift in pixel during one orbit	Measured at pixel
Channel 1	0.1	539
Channel 2	0.14	605
Channel 3	0.07	334
Channel 4	0.07	335

During one of the test phases, the calibration lamp was switched on for four hours. The influence of the related slowly increasing temperature of the optical bench was measured during this phase. In general, it is small compared to the overall shift due to the orbital swing in temperature.

5.10 Pointing Performance

5.10.1 Pointing Error Budget

The pointing budget as presented in the GOME on ERS 2 overall pointing budget is subdivided into different cases. The figures are given for the x, y, and z axes of ERS-2.

The pointing budget for static nadir pointing is given for the beginning of life:

Contribution	x (pitch) axis [deg]	y (roll) axis [deg]	z (yaw) axis [deg]
Non-static	0.067	0.077	0.09
Static	0.223	0.148	0.268
Overall Pointing Error	0.290	0.225	0.358

The pointing budget for nadir scanning:

Contribution	x (pitch) axis [deg]	y (roll) axis [deg]	z (yaw) axis [deg]
Non-static	0.091	0.097	0.091
static	0.185	0.145	0.268
Overall Pointing Error	0.276	0.242	0.359

The pointing budget for the sun pointing mode (without scan unit contributions):

Contributions	x (pitch) axis [deg]	y (roll) axis [deg]	z (yaw) axis [deg]
Non-static	0.064	0.072	0.089
Static	0.124	0.149	0.215
Overall Pointing Error	0.188	0.221	0.304

5.10.2 Pointing Error Rates

Pointing error rates have been assessed as:

in (pitch) x axis: 1.277 mdeg/s
in (roll) y axis: 0.607 mdeg/s
in (yaw) z axis: 1.127 mdeg/s

5.10.3 Influence of Pointing and Mapping Errors and Slit Image on Earth

Pointing errors of both the satellite platform and the instrument cause a distortion of the instantaneous field of view, which is determined by the projection of the entrance slit on the earth's surface.

The distortion of the slit is dominated by the influence of earth curvature. Pointing errors account for changes on the ten-meter range while earth curvature at the extreme points of the scan (+/- 30 deg) are in the range of a kilometre.

The deviation of a 2 km by 40 km slit in nadir view, compared to the extreme swath position, is +0.9 km across track and +7.2 km along track.

5.11 Resource Demands

The actual resource demands of the FM instrument, as built, are:

mass: 55.3 kg (including thermal and interfacing hardware)

volume: 786 mm x 634 mm x 380 mm (x * y * z)
(radiator height 468 mm in z)

power: idle mode 14 W
normal operations 26 W
lamp calibration 31 W

heater power: off mode 13 W
safe mode 23 W (36 W maximum)

data rate: 43 kbps

6. Instrument Calibration

6.1 General

Calibrations are performed to obtain data which are applied (as necessary) to correct in-orbit measurements to arrive at correct measurement values. Characterisation is the investigation of parameters which are not applied in the data processing immediately (i.e., because the real values can be obtained only in orbit) but where it is of interest to know them (e.g.. in order to assess the effect of environmental change from ground to orbit).

The focus of the principal ground calibration exercise is on those parameters which are essential for data processing, but which cannot be measured in orbit (but are also not supposed to change from ground-to-orbit).

6.2 Rationale for Calibration; Calibration Requirements

Calibration is the assembly of measurements and other activities to allow, with sufficient accuracy, the transformation of raw in-orbit data (level 0) of a representation in physical quantities to the raw data input of binary units as a function of pixel number. Also included within the definition of calibration are several additional measurements needed in order to be able to make full use of the physical quantities. Examples of those additional measurements are the Ring effect and the observations of molecular cross-sections.

Figure 6.2-1 diagrams the processing path of raw data into physical quantities and other refined products. The starting point here is raw data (binary units as a function of pixels). With proper wavelength calibration, these data are converted into binary units as a function of wavelength. With proper polarisation calibration, the influence of instrument polarisation properties is removed, yielding binary units corrected for polarisation as a function of wavelength. The data can then be processed further in two ways:

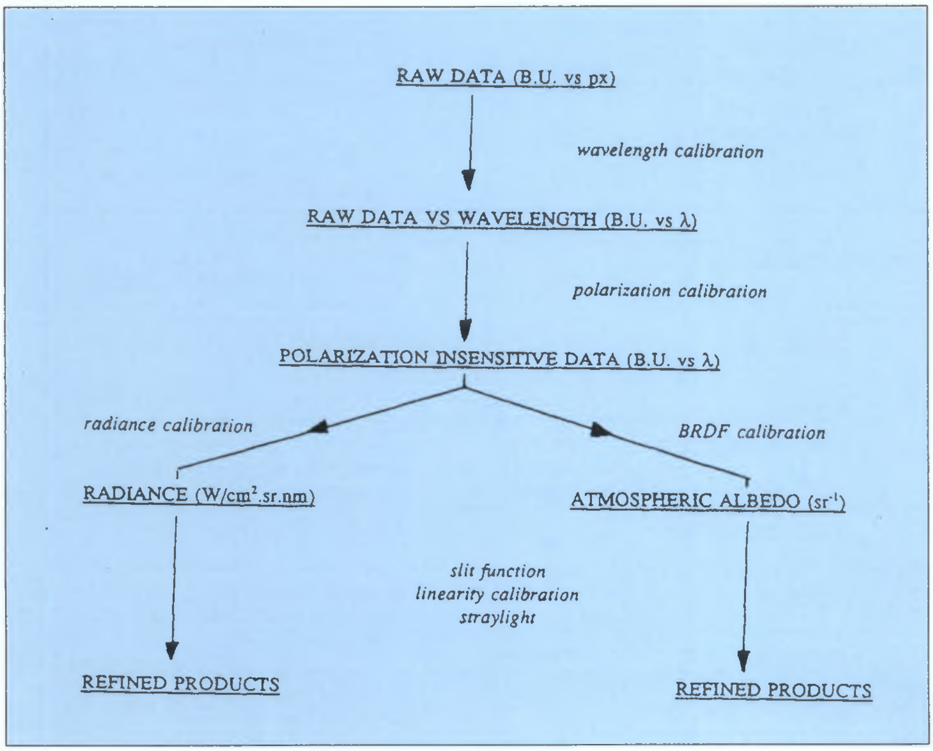


Figure 6.2-1 Processing raw data into physical quantities and refined products
B.U. = binary unit(s); px = pixel(s)

a. into radiances (in W/cm^2 sr nm) as a function of wavelength; for this step a radiance calibration is required;
b. into atmospheric albedo (in sr^{-1}) as a function of wavelength; for this step the BRDF calibration of the GOME Calibration Unit (CU) is needed.

In addition to these primary calibration functions, as shown in Figure 6.2-1, instrument characterisations are undertaken such as characterisations of field-of-view, noise, instrument stability, and so on.

A condensed listing of calibration/characterisation requirements as used for GOME FM/FSM is presented in Table 6.2-2.

1.	BRDF of CU	± 1%	crucial for BUV technique; independent check by means of items #3 and #4; polarisation sensitivity to be included
2.	Polarisation properties	± 1%	includes responses of channels 1-4 and PMD outputs; influence of scan mirror to be included
3.	Spectral radiance	overall accuracy ± 3.0 - 3.5% overall reproducibility ± 1%	
4.	Spectral irradiance	overall accuracy ± 3.0 - 3.5% overall reproducibility ± 1%	
5.	Wavelength calibration	± 0.05 px; goal ±0.02 px	crucial for DOAS technique
6.	Spectral resolution and slit function	± 0.1 px on FWHM	
7.	Stray light	± 0.3 - 0.4%	GOME requirement for stray light is < 1%
8.	FoV and near-field scattered light	± 0.2 - 0.4%	also to be included: effects on radiometric response and on spectral calibration when partially illuminated FoV
9.	Overall noise	± 0.1 B.U.	for scientific channels as well as for PMDs
10.	Linearity	± 0.2 - 0.4%	
11.	Diffuser reflectance	< 1% for an individual calibration	in-orbit long term changes shall be known with an accuracy of ±0.2% per year
12.	Molecular reference spectra		crucial for DOAS technique
13.	Zenith sky		zenith sky observations provide information on Ring effect
14.	Alignment	± 0.05 deg.	
15.	Light tightness		to be demonstrated before starting actual calibrations

Table 6.2:2 Summary of GOME calibration requirements.

6.3 Calibration Facility

The aim of the preflight calibrations was to determine with sufficient accuracy the primary calibration functions and other instrument characterisations as outlined in Table 6.2-2. For GOME, the majority of calibrations were performed with the instrument in air. This was possible for GOME because the focal plane assemblies could be evacuated, allowing the instrument in air to operate with detectors cooled to -38°C. Supporting measurements from the instrument thermal vacuum test provided information on changes due to the transition from air to vacuum, and on changes due to the influence of temperature. The preflight Calibration Facility included:

- a double-monochromator, featuring a collimated output beam of a high degree of uniformity, with low stray light and low residual polarisation, which covered the wavelength range of interest for GOME;

- a white-light set-up, producing multi-spectral diffuse light with low residual polarisation

- a Brewster polariser, enabling linear polarisation of light over a large spectral range (UV + VIS + near IR)

- a radiance/irradiance detector unit, enabling the detection of radiance as well as of irradiance using the same optical components and detector

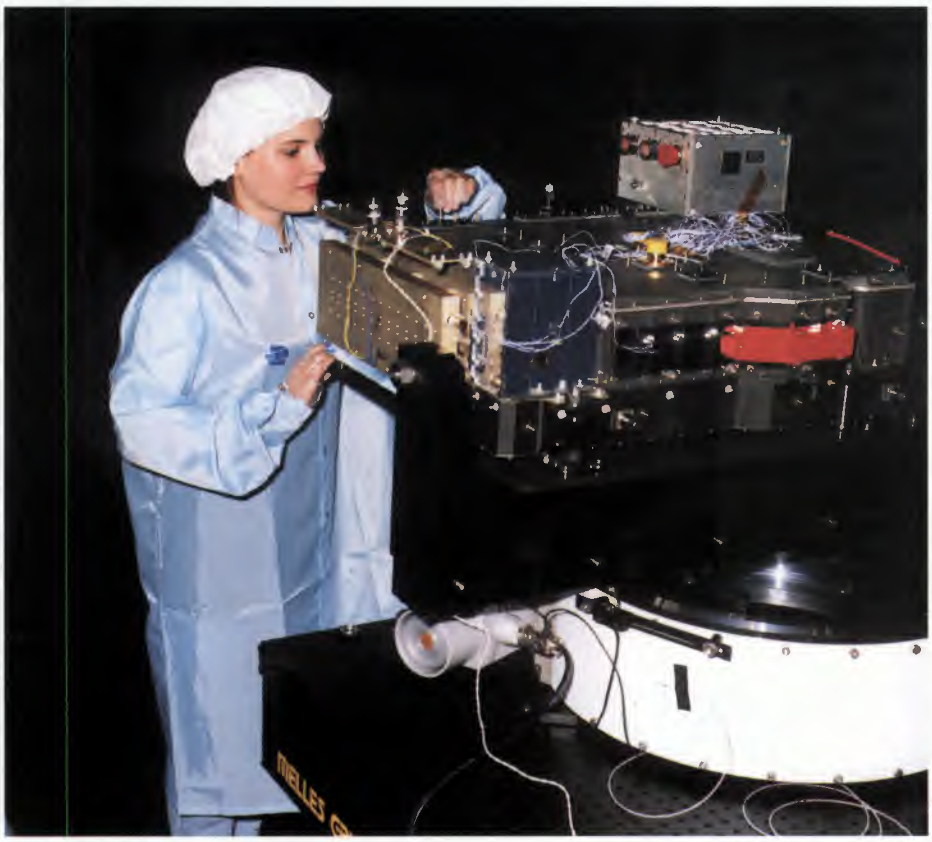


Figure 6.3-1 The GOME instrument mounted on the large turntable in the Calibration Facility

- standards for spectral irradiance, traceable to the National Institute of Standards and Technology (NIST), USA

- a large turntable onto which the instrument was mounted, in particular to characterise the polarisation properties as a function of the scan angle

An optical test unit was developed for use during the thermal-vacuum test at instrument level, providing white diffuse light to GOME during the test; the unit contained a six-band spectral monitoring instrument to check the long-term stability of the unit.

6.4 Flight-Model Calibration Results

In this section, a summary is presented of selected calibration results obtained for GOME FM during preflight calibration.

Bidirectional Reflection Distribution Function (BRDF) of the Calibration Unit

Figure 6.4-1 shows the results obtained for the BRDF calibration of the GOME Calibration Unit flight model. It illustrates that the BRDF is a smooth function over the azimuth and elevation angles of interest of the in-orbit sun calibrations of GOME.

The accuracy analysis for this calibration, based on actual measurements or estimates of all error sources, yields accuracy figures of 1.7% ($\lambda > 270$ nm) and 2.2% (250 nm $< \lambda <$ 270 nm). These figures represent the 99% error interval and might be somewhat pessimistic in view of the actual accuracy achieved. The calibration obtained from the preflight measurements in air are directly applicable to the situation of the in-orbit environment.

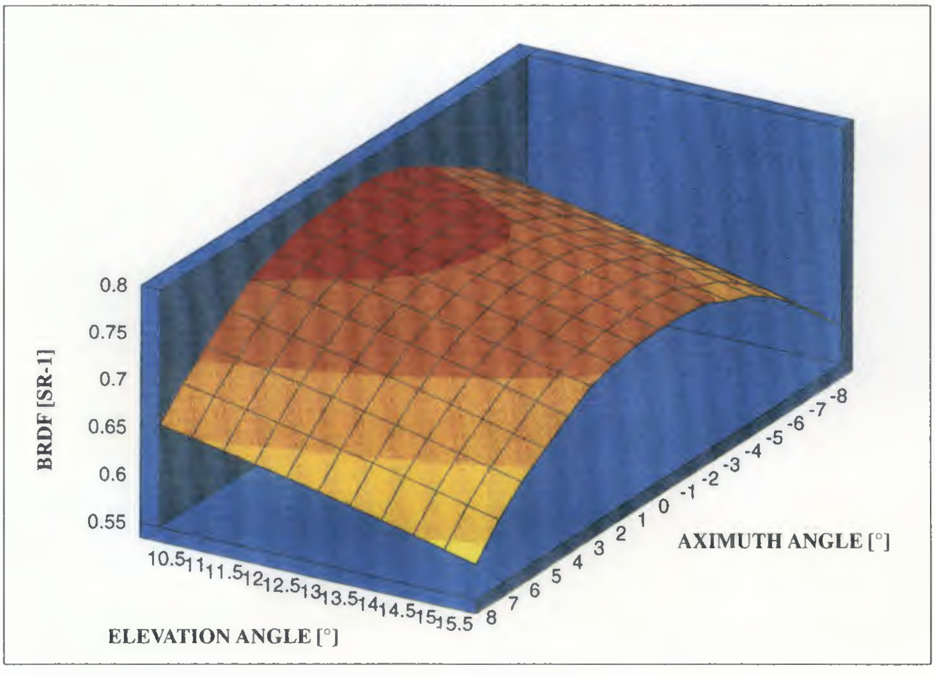


Figure 6.4-1 BRDF of the Calibration Unit

Polarisation Properties

This calibration consisted of a number of different measurements, including the four array detector channels and the three PMD channels of GOME, and also included the influence of the GOME scan mirror. As an example of one of these measurements, the ratio of the response for P polarisation and S polarisation is shown in Figure 6.4-2.

As expected, the instrument showed a pronounced polarisation response. The narrow structures in channel 3 and the phenomenon in the overlap region between channels 3 and 4 are caused by the dichroic beamsplitter used to separate spectrally channels 3 and 4. The figure also clearly shows the influence of the gratings.

For the curve shown in Figure 6.4-2, the accuracy analysis yields figures of 0.34 - 0.83% for channels 2-4 and 0.45 - 3.5% for channel 1. The poor accuracy of 3.5% in channel 1 applies to the low-wavelength part of channel 1 where the preflight and in-orbit measurements were hampered by a lack of signal. Apart from this deviation in channel 1, the accuracies obtained for the calibration of polarisation properties were within specifications. To convert the preflight calibration functions to those for the in-orbit environment, corrections are implemented for:

a. changes in performance of the GOME dichroic channel separator
b. changes in performance of the GOME fused-silica predisperser prism.

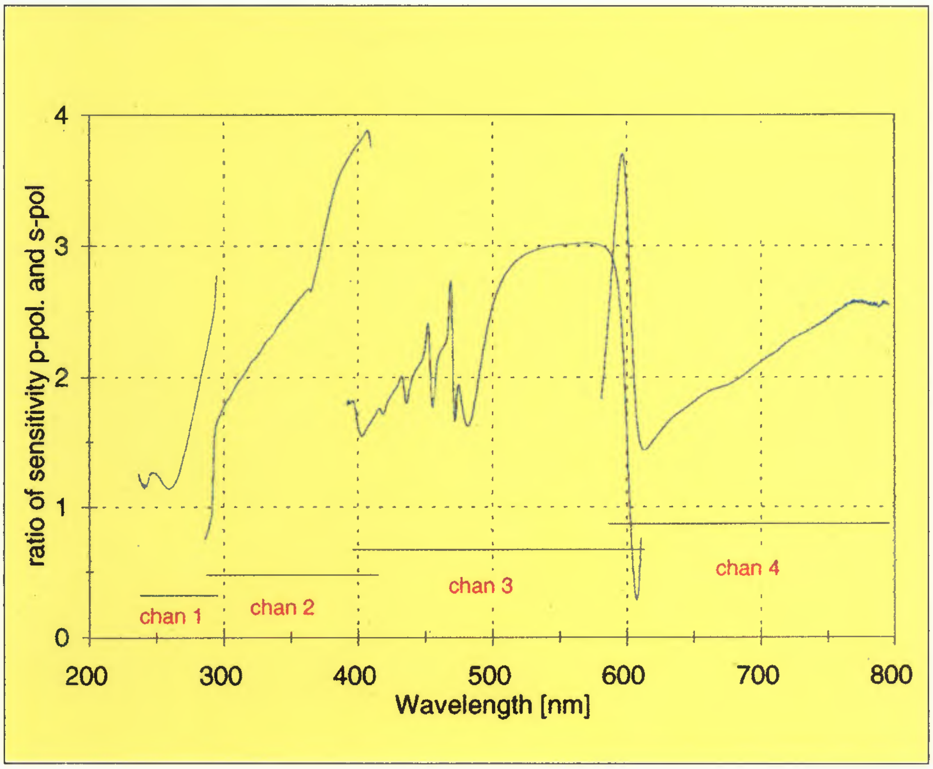
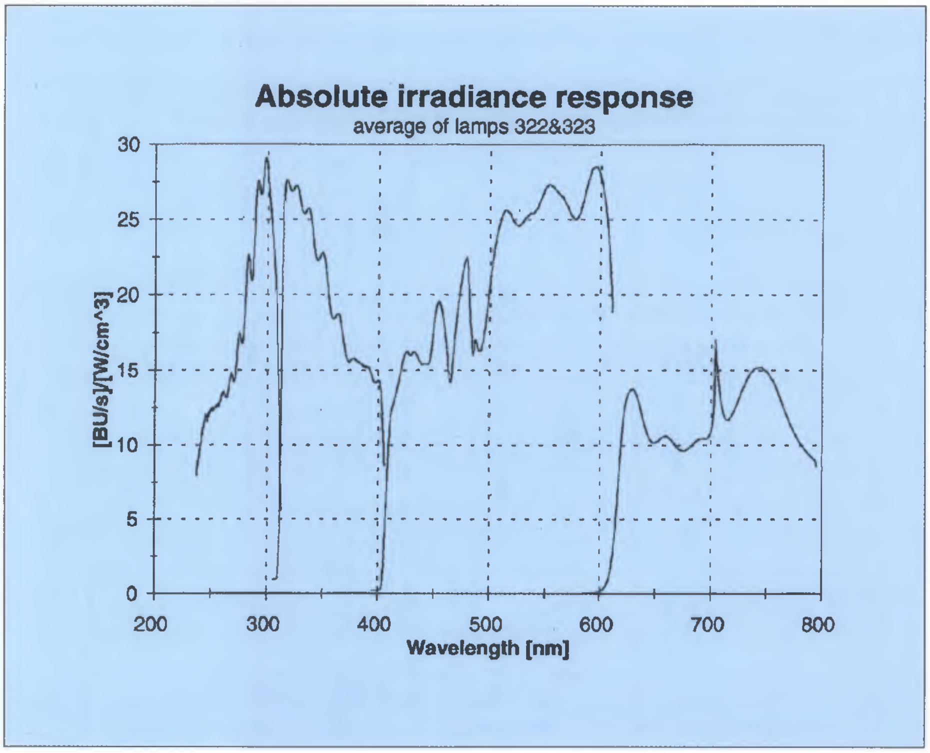


Figure 6.4-2 Ratio of GOME Response for S and P Polarisation

Figure 6.4-3a   Absolute Irradiance Calibration for GOME FM.



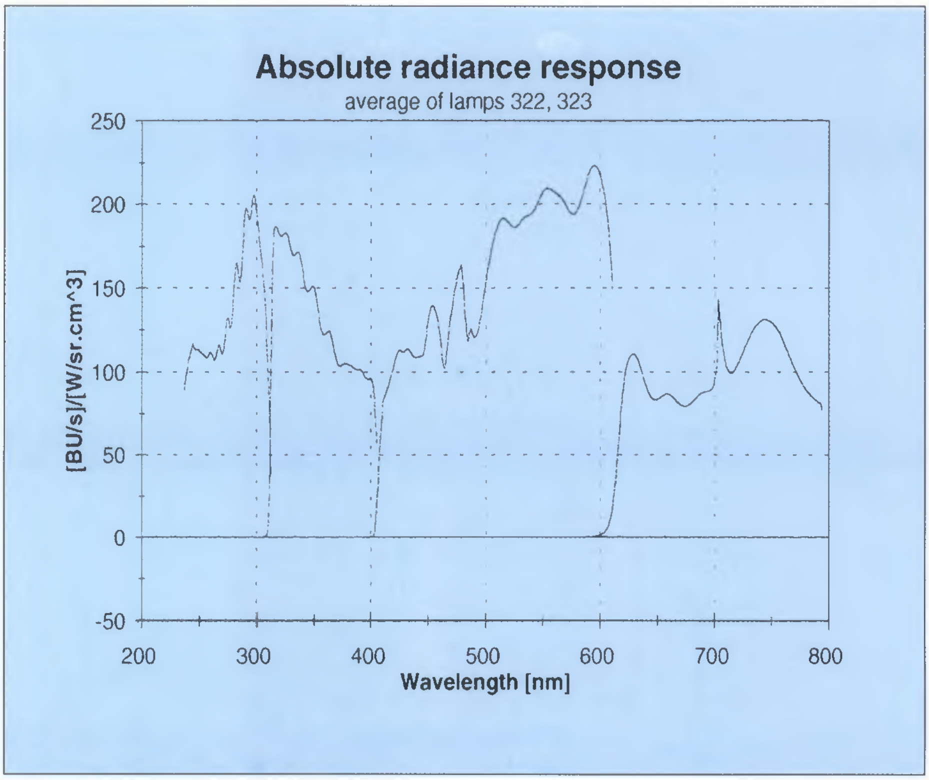


Figure 6.4-3b   Absolute Radiance Calibration for GOME FM

Spectral Radiance / Irradiance

Spectral irradiance of GOME was calibrated using 1000-Watt FEL lamps calibrated for spectral irradiance by the NIST. The spectral irradiance calibration function obtained is shown in Figure 6.4-3a.

The curves in Figures 6.4-3a and -3b show quite erratic behaviour. This is most likely caused by:

a. the so-called etalonning effect (i.e., optical interference effects originating in a thin surface layer of the Reticon detector); this causes a modulation in output with changing wavelength; the effect is shown in an undisturbed way in channel 2 (λ = 300 - 400 nm);
b. irregularities in the spectral region λ = 450 - 500 nm due to the dichroic beam splitter providing the splitting between channels 3 and 4
c. a strong anomaly (a so-called Wood's anomaly) around λ = 700 nm, due to the grating of channel 4.

Apart from these spikes, peaks and valleys, the figures also display changes in optical efficiencies of the gratings within the GOME spectral channels.

The ratio of the irradiance response function and the radiance response function theoretically yields the BRDF of the CU. This technique provides an independent check on the direct calibration of the BRDF of the CU. The results are shown in

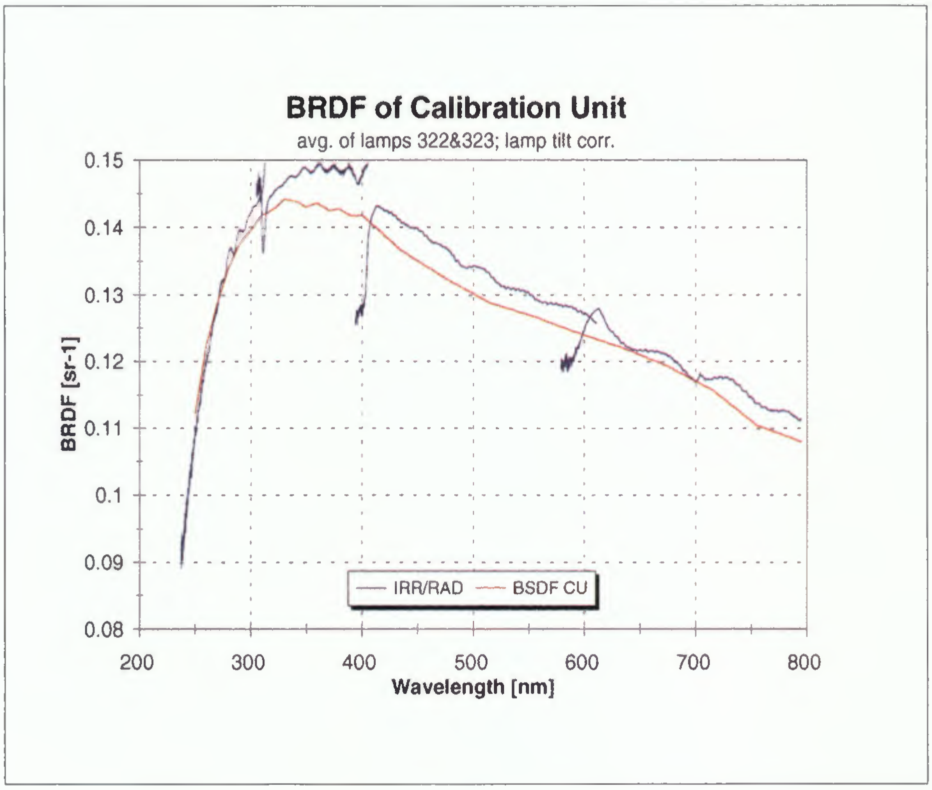


Figure 6.4-4 Comparison Irradiance/Radiance ratio with directly measured BRDF

Figure 6.4-4. The figure shows that in ratioing irradiance and radiance response functions, the etalonning effect and other instrumental features cancel nearly completely and indeed the curve obtained is very similar to the BRDF calibration of the CU. Main deviations occur in the overlap regions, indicating temperature changes between radiance and irradiance calibrations. Apart from that there is a bias between the two curves of approximately 3%.

In cooperation with the NASA Goddard Space Flight Center and ST Systems Corporation (Boulder, Colorado, USA), an effort was undertaken to establish a common radiometric scale between GOME and the U.S. instruments SBUV/2 and SSBUV. The NASA integrating sphere and corresponding light sources and standards used for the calibration of SBUV/2 and SSBUV were brought to the GOME calibration facility to be used for GOME FM. Excellent agreement was observed between the radiance calibration functions obtained by using the GOME radiance standards and those obtained by using the NASA radiance standards; see Figure 6.4-5.

The accuracy assessment gives the following values for the total 99% error intervals:

- absolute spectral radiance 1.6 - 2.7 %
- absolute spectral irradiance 1.5 - 2.7 %
- independent check on BRDF 1.7 - 2.3 %

The high values for each estimate apply to the UV in channel 1. These values are in agreement with the requirements of Table 6.2-2. The comparison with the NASA sphere shows that the radiometric standards as used by NASA for SBUV/2 and SSBUV, and by TPD for GOME, coincide to within ± 1%. The approximately 3% bias observed between the direct calibration of the BRDF of the CU and the independent check from irradiance and radiance calibrations is under further investigation; it is believed that this might be caused by the mesh in front of the diffuser in conjunction with the particular measurement set-up.

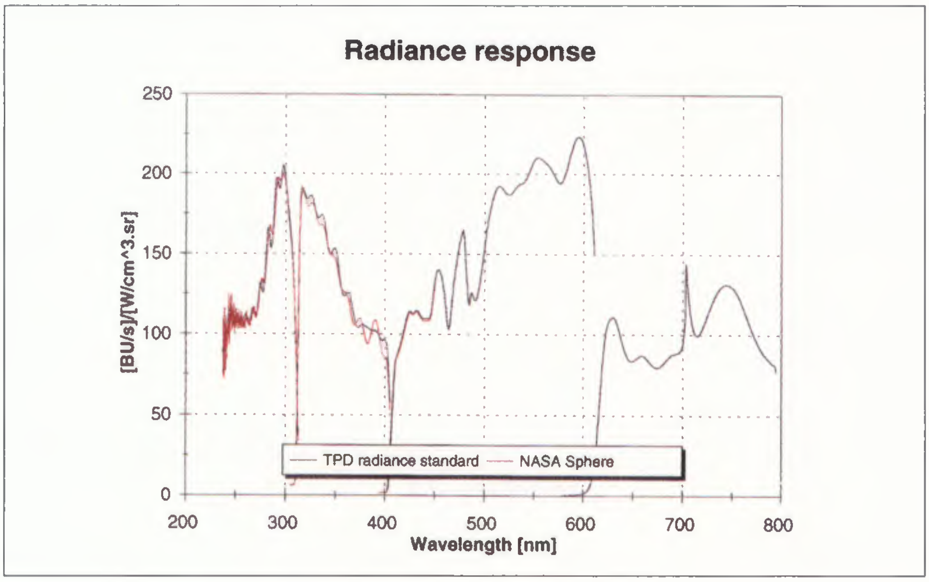


Figure 6.4-5 Radiance Cross Calibration between GOME standards

To convert the preflight calibration functions for radiance and irradiance to the in-orbit environment, corrections are implemented for:

a. changes in performance of the GOME dichroic separator
b. changes in performance of the GOME fused-silica predisperser prism
c. change in etalonning structure between the preflight situation and the in-orbit situation (to be determined during in-orbit GOME commissioning).

Wavelength Calibration

During the thermal-vacuum test of GOME at instrument level, spectra of the onboard Pt-Cr/Ne hollow cathode calibration lamp were recorded. These observations provided a wavelength calibration for each of the four GOME channels at different temperatures in vacuum. The wavelength calibration for each channel is described by means of a 4th-order polynomial. The deviations from this curve for the individual reference lines amounts to 0.02 - 0.03 pixel. This result is in agreement with the accuracy requirements given in Table 6.2-2.

Slit Function

By using the onboard Pt-Cr/Ne lamp and an external mercury lamp, many spectral profiles under different conditions were obtained. From these observations, analytic functions were deduced to represent the so-called slit function (the overall spectral response function of GOME for monochromatic input) for in-orbit conditions.

Stray Light

By illuminating GOME at various wavelengths, stray light was measured in the

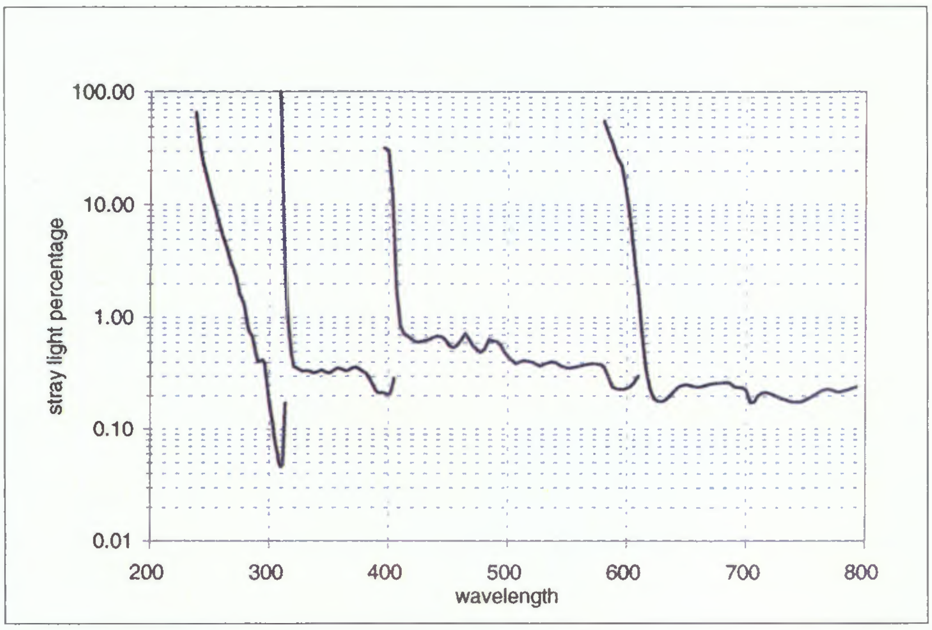


Figure 6.4-6 Expected in-orbit stray light levels

output of GOME at other wavelengths. Contributions from two types of stray light were distinguished: ghost images (due to parasitic reflections) and diffuse stray light. From the measurements and the expected in-orbit flux levels, the expected in-orbit stray light levels were calculated. Results are shown in Figure 6.4-6; the figure shows that the 1% relative stray light requirement is generally met for GOME FM, except for the overlap regions (when the signal becomes small) and the short wavelength part of channel 1.

Field of View (FoV) Characteristics

The variability in the radiometric response and spectral shift in the along-slit direction was measured. This is of particular interest for the lunar calibration, as the Moon only partially fills the spectrometer slit. The design parameters for the GOME FoV are 0.14° x 2.8°. Under normal observational conditions, the entire slit and the entire GOME pupil are illuminated. However, when the Moon is observed, only a fraction of the slit is illuminated. For that reason, several scans of the FoV were made using collimated light as input for the GOME telescope. These measurements provided information on:

- actual dimensions of the FoV
- out-of-field scattered light
- influence on radiometric response and on wavelength scale when only a fraction of the FoV is illuminated.

An example of results obtained from these characterisations is shown in Figure 6.4-7.

6.5 Spectroscopic Measurements

In order to retrieve the trace gases for which GOME has been developed, it is necessary to fit the measured spectrum with reference spectra (absorption cross-sections) of the substance under investigation (see Chapter 9.5). In principle, these reference spectra should

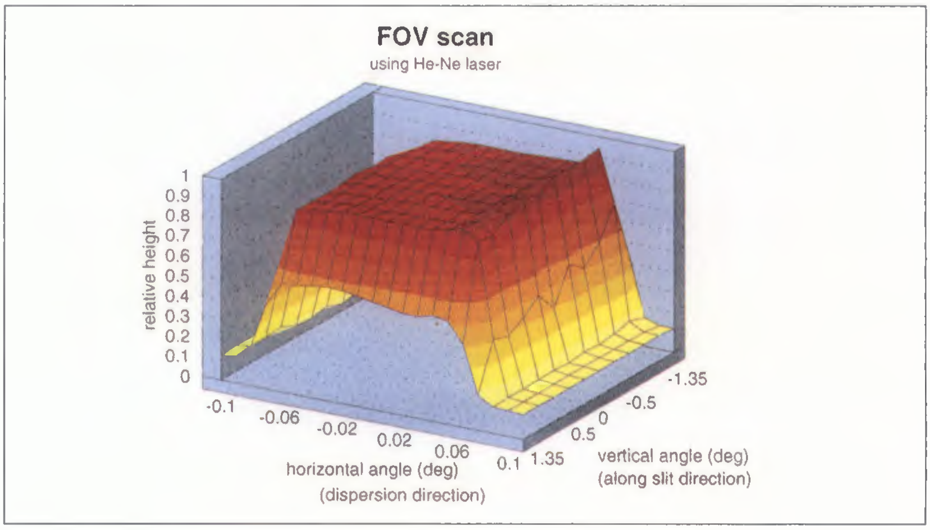


Figure 6.4-7 Characterisations of Field of View (FoV)

be independent of the instrument by which they are measured, but in reality they depend strongly upon the resolution of the instrument. Therefore, ideally one would like to measure the reference spectra of all substances which can possibly be detected (see /6/) by the instrument itself. However, this is not possible, as quite a number of these substances are very difficult to measure and the time available to perform measurements with a Flight Model is naturally very limited. Hence, only the most important measurements have been performed with the Flight Model, after having previously been executed on the BBM. The substances which have been measured were ozone and NO_2 at different temperatures, and SO_2.

In order to perform the measurements, the CATGAS (Calibration Apparatus For Trace Gas Spectra, developed by IFE Bremen) was optically coupled to GOME by an optical fibre and a small telescope. Figure 6.5-1 shows a schematic drawing of this apparatus and Figure 6.5-2 is a photograph of the set-up.

The measured spectra compare quite well with previously recorded ones and, in most cases, the variations can be attributed to differences in spectral resolution /7/. As an example, Figure 6.5-3 shows the comparison of part of an NO_2 spectrum with literature data. (This spectrum was recorded with the BBM; evaluation of absolute cross-sections from FM measurements was still underway at press time.) Figure 6.5-4 shows the temperature dependence of the ozone Huggins Bands as recorded with the FM.

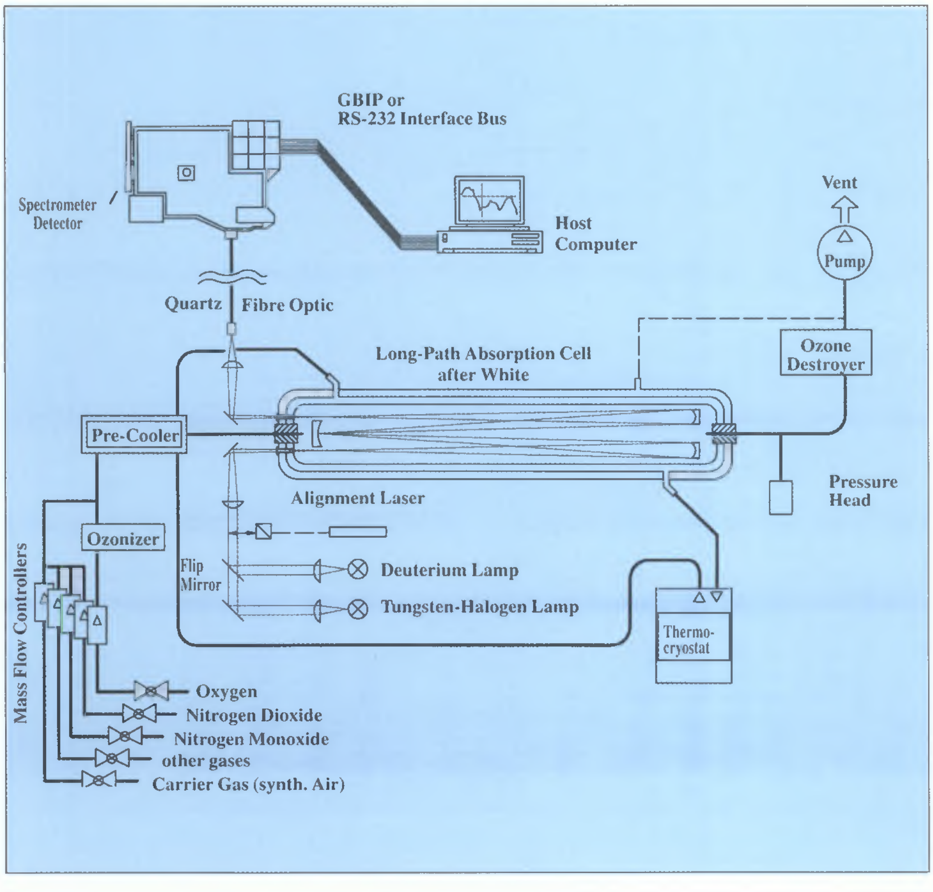
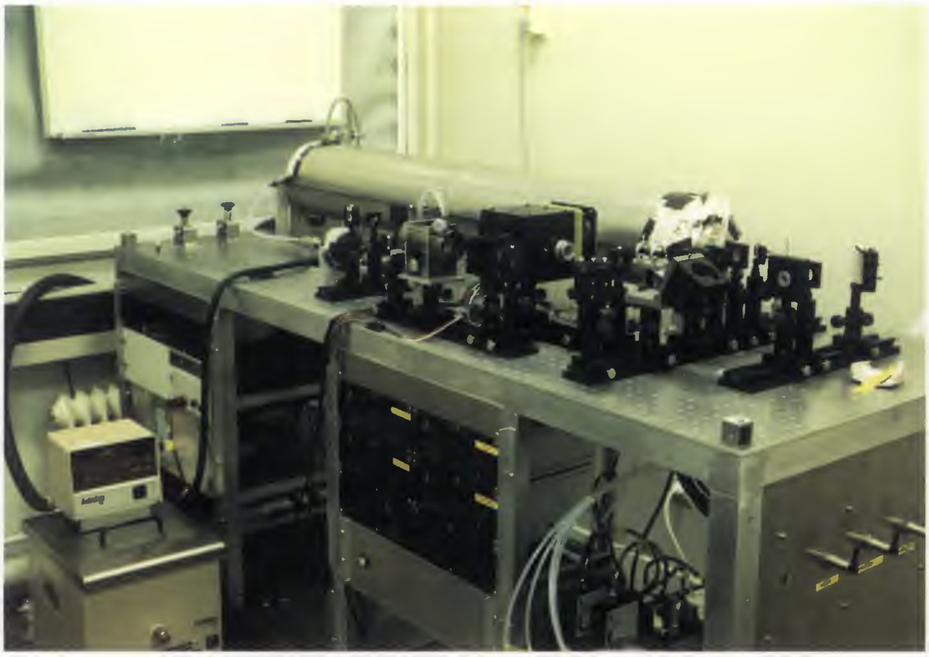


Figure 6.5-1: Schematic of the Calibration Apparatus for Trace Gas Spectra (CATGAS)

Figure 6.5-2 Calibration Apparatus for Trace Gas Spectra (CATGAS)



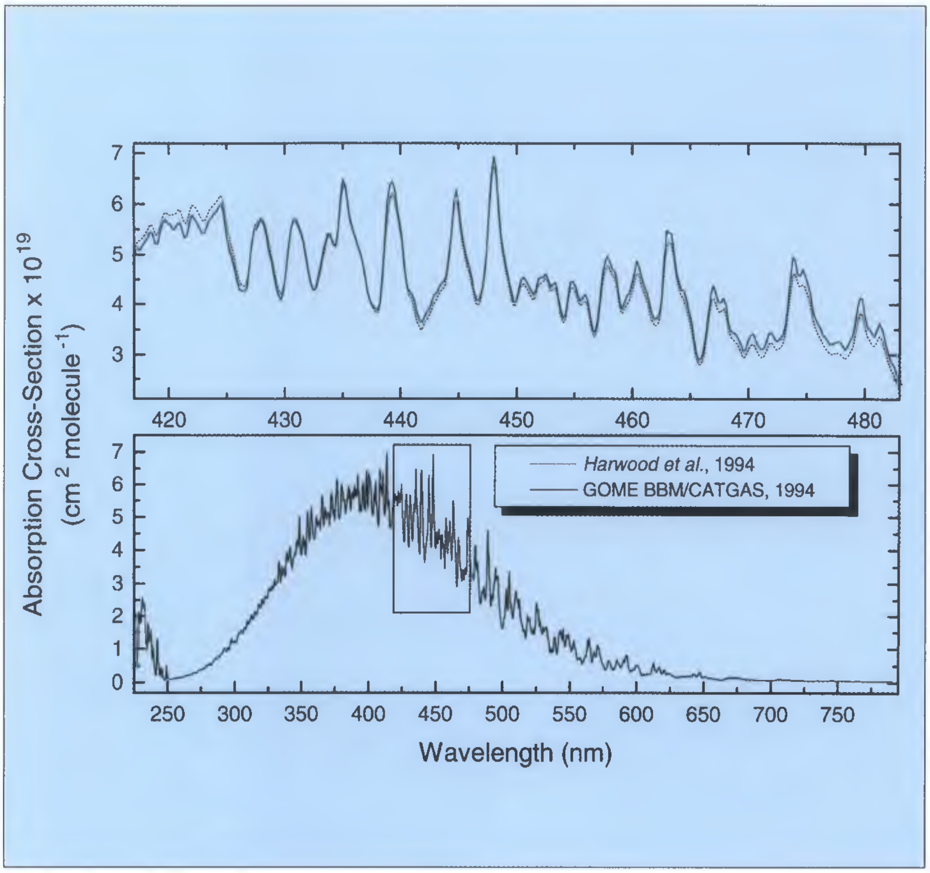


Figure 6.5-3 Comparison of NO_2 spectrum portion with literature data.

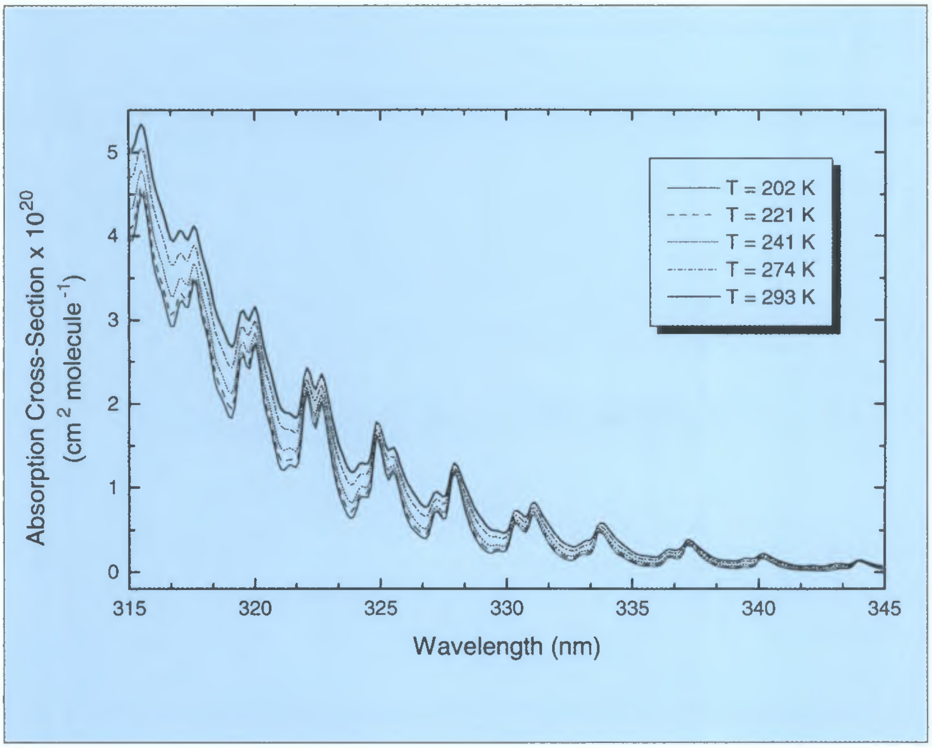


Figure 6.5-4 Temperature dependence of the ozone Huggins Bands as recorded with the FM

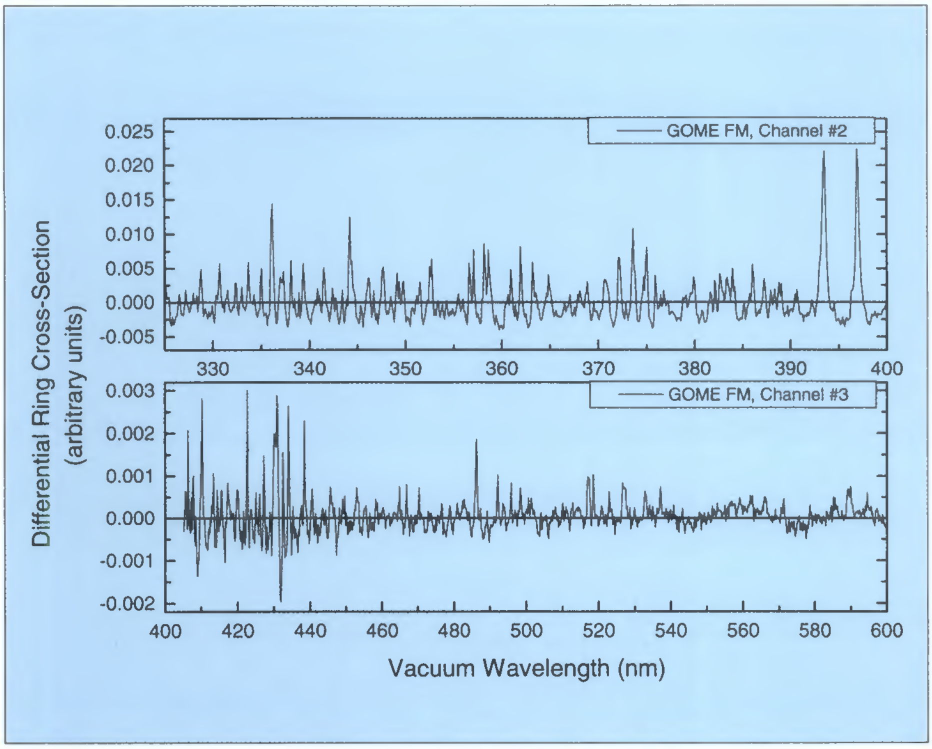


Figure 6.5-5 Ring spectrum as measured with the GOME FM.

Another feature required for the retrieval process is the so-called Ring spectrum /7/, which is treated as a quasi-absorption spectrum. The measurement is done by observing Zenith sky measurements at two orthogonal polarisation directions and ratioing the measured spectra. Figure 6.5-5 shows such a Ring spectrum as measured with the GOME FM.

7. Command and Control, Data Formats

7.1 Command Word Structure

As outlined in Chapter 4.8, commanding of the GOME instrument is by means of the "GOME Parameter" macrocommand through the DEU. The command word is passed from the DEU to the DDHU and there initiates the respective subsystem settings. The Command Word (CW) consists of 12 bytes, of which the last four bytes contain the ICU time, appended by the DEU, to each CW passed on. Apart from some internal functions (checksum, patch and dump, enabling/disabling of certain functions, etc.), the major impacts of the command word on the operational mode of the instrument are described.

Subsystem Settings

By means of the appropriate bit settings in the CW, the following subsystem switching/settings can be achieved:

Cooler control:	independent for each detector cooling loop; Peltier cooling loop can be commanded to -38°C (default), -20°C (backup) or "off."
Calibration Lamp:	on/off.
Light Emitting Diodes:	on/off.
Scan Mirror Heater:	on/off.
Analog-to-Digital Converter Calibration:	on/off.
Diffuser Shutter:	open/closed.

Scan Unit Mode Settings

Two bytes of the command word command the scan unit. The first two bits define the scan unit mode: off, bias update, fixed position, or scanning mode.

The **bias update** is a fixed value which applies to both fixed position and scanning mode; it accounts for the finite alignment **accuracy** of the instrument on the satellite and the much better measurement accuracy (i.e., knowledge of the residual misalignment). However, it can also be used for other purposes (see Polar Observation Timeline, Chapter 8.2). Sending a bias update value does not lead to an immediate change but, rather, it is memorised and only becomes active when the next command is received.

If the **'fixed position'** bit is set, the following 14 bits specify the fixed position to which the scan mirror is driven in the last 1.5-sec interval of a 6-sec period. For the most important fixed positions, see Chapter 4.6, Fig. 4.6-4.

If the '**scanning mode**' bit is set, the following bits contain the code for the various scan angle ranges which are required (see Chapters 3 and 4.6).

Integration Time Settings

A total of three bytes is used to set the integration times of the Reticon array detectors independently for each channel's respective bands (channels 1 and 2 have two bands each).

In general, two commands are required: one called 'base' value and the other called 'trim' value. They specify cells in a look-up table stored in the DDHU, which contains a total of 256 possible integration time values (Table 7.1-1). Most of these values will never be needed; but in this way there is sufficient flexibility to adapt the integration times of each individual band to the prevailing illumination conditions in the various observational and calibration modes.

(Note that for atmospheric measurements in the UV, only multiples of six seconds make sense, because otherwise the scan pattern becomes asynchronous, leading to irregularly-shaped ground pixels.)

7.2 Timelines in the DEU

Illumination conditions of the Earth change significantly around an orbit, requiring frequent updates of integration time settings in order to achieve optimum signal-to-noise without risking saturation of the detectors. To avoid heavy traffic on the command uplink which may result from these updates, the DEU can store three timelines onboard (see Chapter 4.8).

A timeline is a sequence of up to 30 Command Words and time delays with respect to the start time of the timeline, together with a header field specifying the timeline number (1, 2 or 3), start time, and a 'loop' parameter. The loop parameter permits repetition of the same timeline up to 16 times without the need to uplink a new command. When sending the command word, the actual ICU time is appended, as is done for 'direct' commanding.

Three default timelines are defined:

Normal Observation Timeline (NOT)
Optimises integration time settings around the orbit and performs dark current measurements on the night side.

Sun Observation Timeline (SOT)
Similar to the NOT, but with a period of 42 sec inserted close to the North Pole pass in order to perform sun calibration.

Table 7.1-1: Integration time in seconds versus trim and base.

Trim table		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
(*93.73ms)		*0*	*1*	*2*	*4*	*8*	*16*	*32*	<u>*64*</u>	*128*	*256*	*512*	*1024*	*2048*	*4096*	*8192*	*16384*
base table (*93.75ms)																	
0	**1**	.09375	.18750	.28125	.46875	.84375	1.59375	3.09375	6.09375	12.09375	24.09375	48.09375	96.09375	192.09375	384.09375	768.09375	1536.09375
1	**2**	.18750	.28125	.37500	.56250	.93750	1.68750	3.18750	6.18750	12.18750	24.18750	48.18750	96.18750	192.18750	384.18750	768.18750	1536.18750
2	**4**	.37500	.46875	.56250	.75000	1.12500	1.87500	3.37500	6.37500	12.37500	24.37500	48.37500	96.37500	192.37500	384.37500	768.37500	1536.37500
3	**8**	.75000	.84375	.93750	1.12500	1.50000	2.25000	3.75000	6.75000	12.75000	24.75000	48.75000	96.75000	192.75000	384.75000	768.75000	1536.75000
4	**16**	1.50000	1.59375	1.68750	1.87500	2.25000	3.00000	4.50000	7.50000	13.50000	25.50000	49.50000	97.50000	193.50000	385.50000	769.50000	1537.50000
5	**32**	3.00000	3.09375	3.18750	3.37500	3.75000	4.50000	6.00000	9.00000	15.00000	27.00000	51.00000	99.00000	195.00000	387.00000	771.00000	1539.00000
6	**64**	6.00000	6.09375	6.18750	6.37500	6.75000	7.50000	9.00000	12.00000	18.00000	30.00000	54.00000	102.00000	198.00000	390.00000	774.00000	1542.00000
7	**128**	12.00000	12.09375	12.18750	12.37500	12.75000	13.50000	15.00000	18.00000	24.00000	36.00000	60.00000	108.00000	204.00000	396.00000	780.00000	1548.00000
8	<u>**256**</u>	24.00000	24.09375	24.18750	24.37500	24.75000	25.50000	27.00000	<u>30.00000</u>	36.00000	48.00000	72.00000	120.00000	216.00000	408.00000	792.00000	1560.00000
9	**512**	48.00000	48.09375	48.18750	48.37500	48.75000	49.50000	51.00000	54.00000	60.00000	72.00000	96.00000	144.00000	240.00000	432.00000	816.00000	1584.00000
10	**1024**	96.00000	96.09375	96.18750	96.37500	96.75000	97.50000	99.00000	102.00000	108.00000	120.00000	144.00000	192.00000	288.00000	480.00000	864.00000	1632.00000
11	**2048**	192.00000	192.09375	192.18750	192.37500	192.75000	193.50000	195.00000	198.00000	204.00000	216.00000	240.00000	288.00000	384.00000	576.00000	960.00000	1728.00000
12	**4096**	384.00000	384.09375	384.18750	384.37500	384.75000	385.50000	387.00000	390.00000	396.00000	408.00000	432.00000	480.00000	576.00000	768.00000	1152.00000	1920.00000
13	**8192**	768.00000	768.09375	768.18750	768.37500	768.75000	769.50000	771.00000	774.00000	780.00000	792.00000	816.00000	864.00000	960.00000	1152.00000	1536.00000	2304.00000
14	**16384**	1536.00000	1536.09375	1536.18750	1536.37500	1536.75000	1537.50000	1539.00000	1542.00000	1548.00000	1560.00000	1584.00000	1632.00000	1728.00000	1920.00000	2304.00000	3072.00000
15	**32768**	3072.00000	3072.09375	3072.18750	3072.37500	3072.75000	3073.50000	3075.00000	3078.00000	3084.00000	3096.00000	3120.00000	3168.00000	3264.00000	3456.00000	3840.00000	4608.00000

Calibration Timeline (CAT)
Used to perform wavelength calibrations, diffuser characterisation and detector performance monitoring.

Additional timelines will be used during the Northern and Southern spring periods: these are like normal observation timelines, except that in the polar regions the 'bias' feature of the scan unit command is used to also cover the regions up to the poles. (Normal across-track scans would leave a coverage hole of about 8° latitude about the poles.) Detailed settings of the timelines, as conceived prior to launch, are given in Appendix A. The use of timelines in routine operations is described in Chapter 8.

7.3 Housekeeping Telemetry and Monitoring

To monitor proper execution of commands and to obtain general information on the instrument's status and health, a number of housekeeping and status data are acquired by the DDHU and forwarded via S-band to the ground. (For the detailed routing, see Chapter 9.) In addition to the 'command echo' and status flags for the various subsystems, it is comprised of:

- data from Polarisation Monitoring Detectors (3 channels, 16 readings each every 1.5 sec);
- scan unit position and motor current (16 readings each every 1.5 sec);
- FPA temperatures (four readings for each of the four PFAs every 1.5 sec);
- other temperature readings (every 1.5 sec):
    - charge amplifier
    - polarisation unit
    - scan mirror, motor, electronics
    - calibration lamp and power supply
    - sun diffuser
    - DDHU analogue chains, DC/DC converter, PLT board, PRL board
    - external radiator
    - four positions on the optical bench
    - predisperser prism
- calibration lamp voltage and current (every 1.5 sec);
- three sample pixels per band of the Reticon detectors;
- acquisition chain offset.

Acquisition and transmission of these data enable control functions to be executed by the DDHU (e.g., detector cooling loop), automatic surveillance by DDHU (e.g., lamp ignition status) or DEU (GOME status monitoring), and health checks and performance evaluations (e.g., thermal control subsystem) by the ground control centre.

7.4 Science Data Format

The science data also go through the DEU, where GOME data (with their own secondary header) are multiplexed with the ATSR IRR and MWR data and are forwarded to the IDHT (see Chapter 9.1). Because the ATSR data acquisition is driven by the ATSR synchronisation pulse (of approximately 150 ms), the GOME data transmission is also driven by this cycle.

GOME science data are organised into 20 frames of 200 words and are transmitted during a 1.5 sec interval. The first frame contains header information; all subsequent frames have a frame counter in the first word of the frame. Except for the header (which is different), all information described in the previous chapter on housekeeping telemetry is copied in the first frame of each packet.

Frames 2-19 contain all the readouts from the detector pixels. Depending on the integration status of each individual band, one has to distinguish the following cases:

- Integration times shorter than or equal to 1.5 sec: Only the last readout within a 1.5 sec interval is transmitted.
- Integration times longer than 1.5 sec: If a readout has been performed, the data are put in the telemetry. If no readout has been performed, the corresponding fields are filled in with dummy data. Integration status is reported both in the housekeeping information and in the first frame. This also holds true for aborted integration times, in case a new command is received prior to the completion of a running integration.

Because of restrictions in the data rate, not all 4096 pixels of the four detector arrays are transmitted, only 512 pixels in channel 1 are transmitted. Note that some of the pixels in channels 1 and 2 are not supposed to be lit by a part of the spectrum; their contents give at least an indicative measure of stray light levels.

8. Instrument Operation

8.1 General ERS-2 Operations

Operations of the satellite, its payload (including GOME), and the ground stations for command uplink and telemetry reception are performed by the Mission Management and Control Centre (MMCC) at the European Space Operations Centre (ESOC) in Darmstadt, Germany (Figure 8.1-1).

Because of the low-altitude, polar, sun-synchronous orbit of ERS-2, there is no continuous contact with the satellite. Instead, commands are uplinked and telemetry is received in bursts at a high latitude tracking station in Kiruna, Sweden (Figure 8.1-2). Out of the approximately 14 orbits the satellite makes every day, each of 10 orbits have a contact time with Kiruna of at least 10 minutes duration. For the remaining orbits, see Chapter 9.2.

The High Level Operations Plan specifies a number of general rules for the operation of the instruments and the satellite. From this the MMCC establishes the Detailed Mission Operations Plan, taking into account the level of onboard resources, contact times with the ground station, tape recorder operations (see Chapter 9.1), land/ocean/ice masks, illumination conditions, etc. From this plan, the command uplink files are derived and station operations are scheduled. The command file for the satellite is transmitted to Kiruna and then uplinked via S-band transmission to the satellite's onboard computer, which forwards the commands (either directly or time-tagged) to the respective subsystems or Instrument Control Units (in the case of GOME, this is the ATSR-DEU).

8.2 GOME Operations

By default, GOME is operated by means of timelines stored onboard in the DEU (see Chapter 7.2). So, for the routine phase, traffic on the uplink is limited to a few "activate timeline #" commands per day.

Figure 8.1-1 European Space Operations Centre (ESOC) in Darmstadt, Germany

Figure 8.1-2 Kiruna (Sweden) ground station

For 13 out of the 14 orbits per day, the "Normal Observation Timeline" (NOT) will be used. A sun calibration is performed daily by means of the "Sun Observation Timeline" (SOT). Once per month, the "Calibration Timeline" (CAT) will be run for several orbits; for the user, this will be reported as "not available."

Because of the orbit and scan geometry, an area of a few degrees in latitude around the poles is normally not covered (see coverage plots in Appendix D). In order to cover this region in the polar spring-time when the ozone hole develops, special timelines have been generated in which, in the polar regions, the scan mirror is biased sidewards to cover the region up to the poles. The angles for the North and South Poles are slightly different, so a North Pole Observation Timeline (NPOT) and a South Pole Observation Timeline (SPOT) have been generated. During the periods around equinoxes, they will be uplinked to supersede the CAT and then used alternating with the NOT. The normal coverage in polar regions below 82 degrees latitude provides sufficient redundancy such that this scheme does not generate coverage gaps elsewhere. The SOT will still be executed daily. After the ozone hole episode is over, the normal CAT will be reinstalled.

Except for the CAT, all other observation timelines have a duration of one orbit (6030 sec). Timing of the timeline activation is linked to illumination conditions which vary with the seasons; so, from day-to-day, there is a slight change in the activation time with respect to the equator crossing.

8.3 In-Orbit Calibration

Calibration of the instrument and supporting measurements are performed at different levels and with different frequencies:

- Dark current measurements are performed on the night side of every normal observational orbit (except when calibrations are performed);

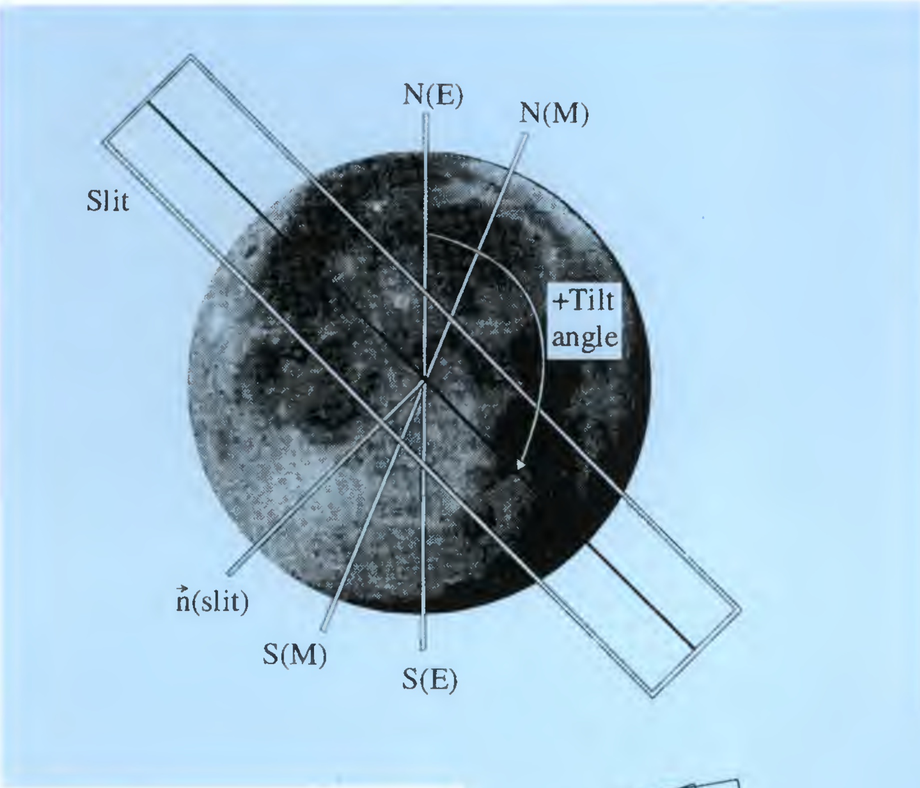


Figure 8.3-1 (a) Geometries of the tilted slit projected to the center of the Moon. N(M) and S(M) are correspondive North and South of Lunar axis, N(E) and S(E) are correspondive North and South of Earth axis projected onto the Moon, n(slit) is the normal vector of slit.

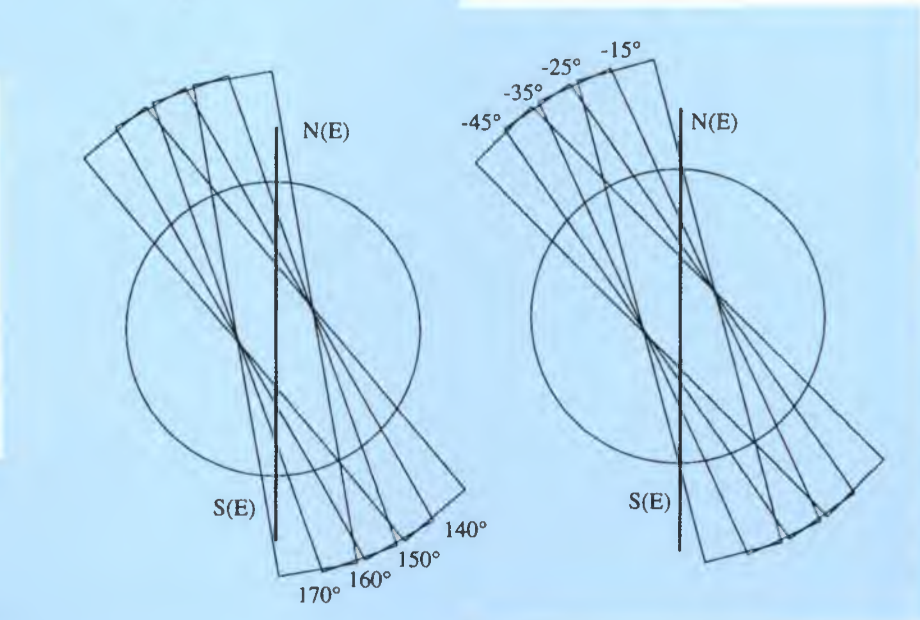


Figure 8.3-1 (b) Definition of the tilt angles

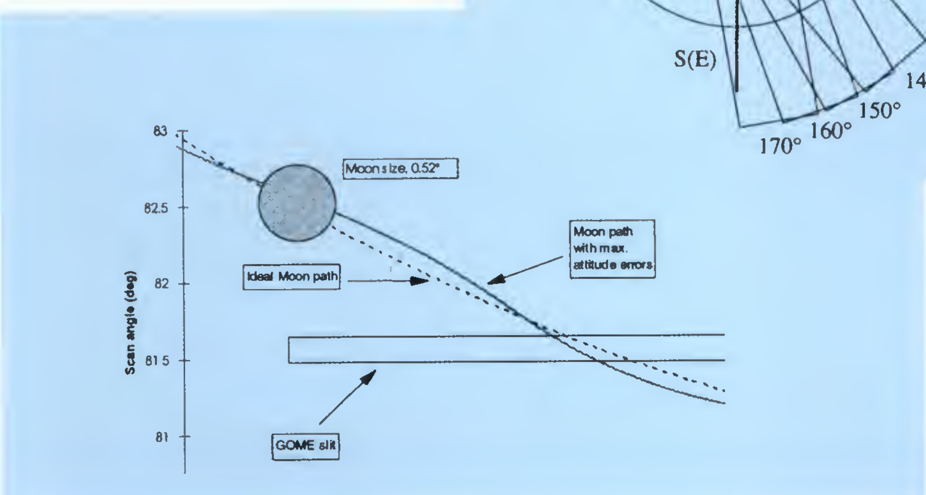


Figure 8.3-1 (c) One ideal and simulated Moon passage across the GOME slit.

- Radiometric calibration, by means of the sun, are performed daily for 42 sec.

- Wavelength calibration is performed once a month by means of the CAT. The spectral lines are mapped all around one orbit; the set of wavelength calibration coefficients as a function of temperature is used to correct each individual spectrum (measurement) for temperature variations as a function of orbital position. The monthly frequency is derived from the expected rate of mean temperature change, which is mainly driven by seasonal changes and by the rate of degradation of thermo-optical surfaces.

- Also within the CAT, some monitoring measurements are performed for diffuser characterisation, fixed pattern characterisation, checks for radiation damage, etc. These data are not routinely applied in the processing.

- In principle, there is the possibility of also performing moon calibrations by pointing the scan mirror sidewards to an angle between 70 and 85 degrees with respect to Nadir. However, there are some problems associated with moon calibrations:

    - Because of the geometric relationships (sun/moon/satellite orbit/instrument viewing range; see Figure 8.3-1), approximately only a 3/4 illuminated moon can be viewed. The lunar phase variation of several degrees introduces some variability, which can be corrected for only in long term series.

    - The number of possible moon observations is not distributed evenly throughout the year, but occurs in clusters, with gaps of up to 6 months between observations.

    - The circular moon disk is much larger than the spectrometer slit width. So the spectrometer slit has to be moved (or is moved by the satellite's motion) across the moon's disk. Because of the limited pointing accuracy and stability, the quality of the recorded spectra must be questioned as to whether they are of use for high-accuracy calibration purposes /4/.

Notwithstanding these difficulties, some initial moon calibration observations will be performed whenever the possibility arises. This will be done by special "Test Timelines" which temporarily override one of the onboard resident timelines.

8.4 Operations during Commissioning Phase

As GOME is the first sensor of its kind, it requires a thorough engineering and scientific evaluation before proceeding to routine operations. This evaluation is done during the commissioning phase, scheduled for the six months following launch, and concludes with a review and assessment of the results obtained by the end of the period.

The present planning subdivides commissioning operations into four phases:

- **Phase 1 (up to L+30 days): Initial Switch-on and Functional Tests.**
  During this period, checks will be performed mainly on the command/control, telemetry formats, and some subsystems. The coolers in the FPAs will **not** be operated during this period; this allows sufficient time for off-gassing and FPA venting.

- **Phase 2 (up to L+60 days): Performance Evaluation and Initial Calibration.** After switch-on of the coolers, all calibration and observation modes will be executed, one by one, to evaluate performance, assess differences between ground and in-orbit calibrations and operations, and to obtain "first data" for the calibration database (see Chapter 9.4).

- **Phase 3 (up to L+90 days): Operations Optimisation.** Using the measurements obtained in phase 2, settings in the various timelines are updated as necessary and operations (with timelines) are executed and monitored. Also, evaluation of the functioning and performance of the data processor begins. (It is expected that from this point, the first preliminary data products will be available to Cal/Val users).

- **Phase 4 (up to the end of commissioning): Data Product Validation.** (See Chapter 10.)

9. Data Flow and Processing

9.1 On-board Data Flow

The science data (as described in Chapter 7.4) from the DDHU are delivered to the ATSR-DEU, where they are formatted into packets, together with IRR and MWR data. These packets are then transmitted to the "Instrument Data Handling and Transmission" system (IDHT), where they are multiplexed with other low bit rate data (from SAR/wave, Scatterometer and Radar Altimeter). During the majority of the orbit, when there is no contact with a ground station, these data are stored on-board on tape recorders (see Figure 9.1-1) at a total rate of 1.1 Mbps. During periods of ground station visibility, the recorder is replayed at 13.6 times the recording speed (in reverse order) and is downlinked at 15 Mbps in the X-band. The downlink is shared with a real-time channel, which transmits those data acquired during the playback period.

Next to the X-band link, there is a second link in the S-band, which downlinks housekeeping information (see Chapter 7.3) and uplinks commands. However, these data are for monitoring by the MMCC only and are not intended for any processing or distribution.

9.2 On-ground Data Flow

Several ground stations are equipped to receive the X-band data: Kiruna (S) (main station), Prince Albert, Gatineau (CDN), Maspalomas (E), and Fucino (I). Data from ten out of fourteen orbits are transmitted to Kiruna every day, resulting in the coverage shown in Figure 9.2-1; data from the other four daily orbit tracks are transmitted to the other ground stations.

The data, arriving in reverse order (tape recorder dump) or correct order (real-time downlink), are sorted and put into the correct sequence in the **"Low Rate Data Processing Facilities"** (LRDPFs), co-located at the receiving ground stations (except for Prince

Figure 9.1-1 The IDHT Tape Recorder for on-board data storage

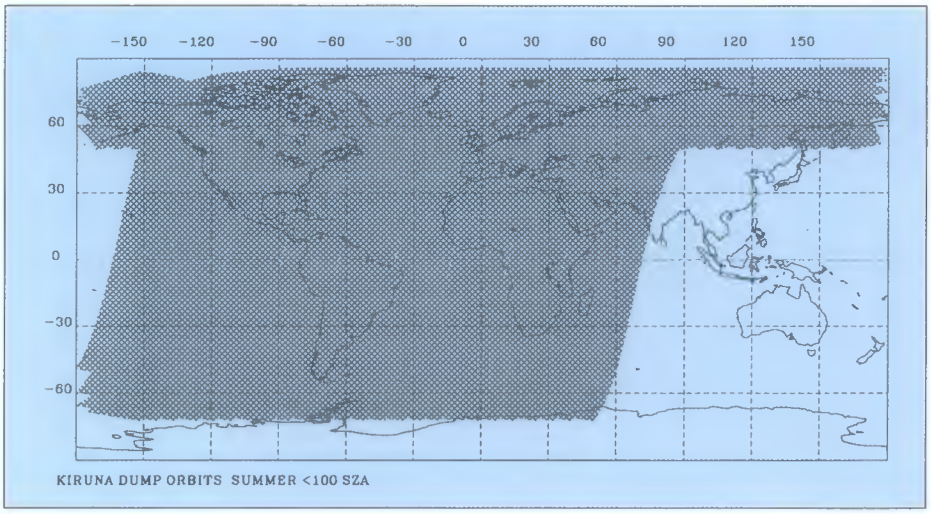


Figure 9.2-1 ERS-2 satellite coverage data transmitted to Kiruna during the commissioning phase

Figure 9.2-2 German Processing and Archiving Facility (D-PAF) at the DRL in Oberpfaffenhofen, Germany.

Albert; those data are processed at Gatineau after physical transport of tapes from Prince Albert to Gatineau). The LRDPF also demultiplexes the data streams from the different instruments and generates Fast Delivery Products for instruments other than ATSR and GOME. The demultiplexed data, together with general information for time correlation, orbit and attitude determination, are then copied on Exabyte cassettes and distributed to the specialised "Processing and Archiving Facilities" (PAFs), and to ESRIN and ESTEC for monitoring purposes.

During the commissioning phase (and possibly depending upon special arrangements for campaign support), the process of data delivery will be accelerated (at least for the Kiruna orbits; see Figure 9.2-1) by not only transporting them by Exabytes, but also by copying them on a BDDN satellite link.

The assigned processing centre for the processing of GOME data is the German Processing and Archiving Facility (D-PAF) at the DRL in Oberpfaffenhofen, Germany (near Munich; see Figure 9.2-2).

9.3 The GOME Data Processor (GDP)

The overall processing scheme of GOME can be broken down into three major elements:

- interfaces with the external world (input and output of the system) via the "Data Management System";
- level 0 -> 1 processing, which generates calibrated spectra from the raw data;
- level 1 -> 2 processing, which computes the total column amounts from the spectra;

The functions and interfaces are described in this chapter; the latter two processes are discussed in the following two chapters.

The Data Management System is a general infra-structure, not limited to GOME but also supporting other data products generated from ERS data. It provides the following functions:

- interfacing with and registration of incoming data (GOME data through Exabyte or BDDN, supporting data for time, orbit, and attitude restitution);
- generation of time correlation, restituted orbit and attitude files;
- archiving of generated products
- cataloguing of the archived products
- reporting to ESRIN (see Chapter 9.6)
- product order handling.

This system has been used already for ERS-1 and is only slightly enhanced to include GOME processing. The dedicated processing system, purchased and commissioned explicitly for GOME, is a network of five Spark 1000 stations, each with eight processors and an internal hard disk for real-time processing. This capacity enables data to be processed, on average, at the same rate as the data arrive, with spare capacity for implementing and testing new algorithms in parallel to the operational processing (or to work off backlogs).

9.4 Level 0 -> 1 Processing

Raw GOME data (Level 0) are converted into "calibrated radiances" (Level 1) by applying calibration algorithms and calibration parameters. The calibration parameters are determined regularly using in-flight data obtained either when the GOME operates during darkness or when lamp, internal LED or sun calibration measurements are taken. In addition, data from the pre-flight instrument calibration activities are required. The extracted calibration parameters are collected into a complete "calibration data base" over the entire lifetime of the GOME sensor.

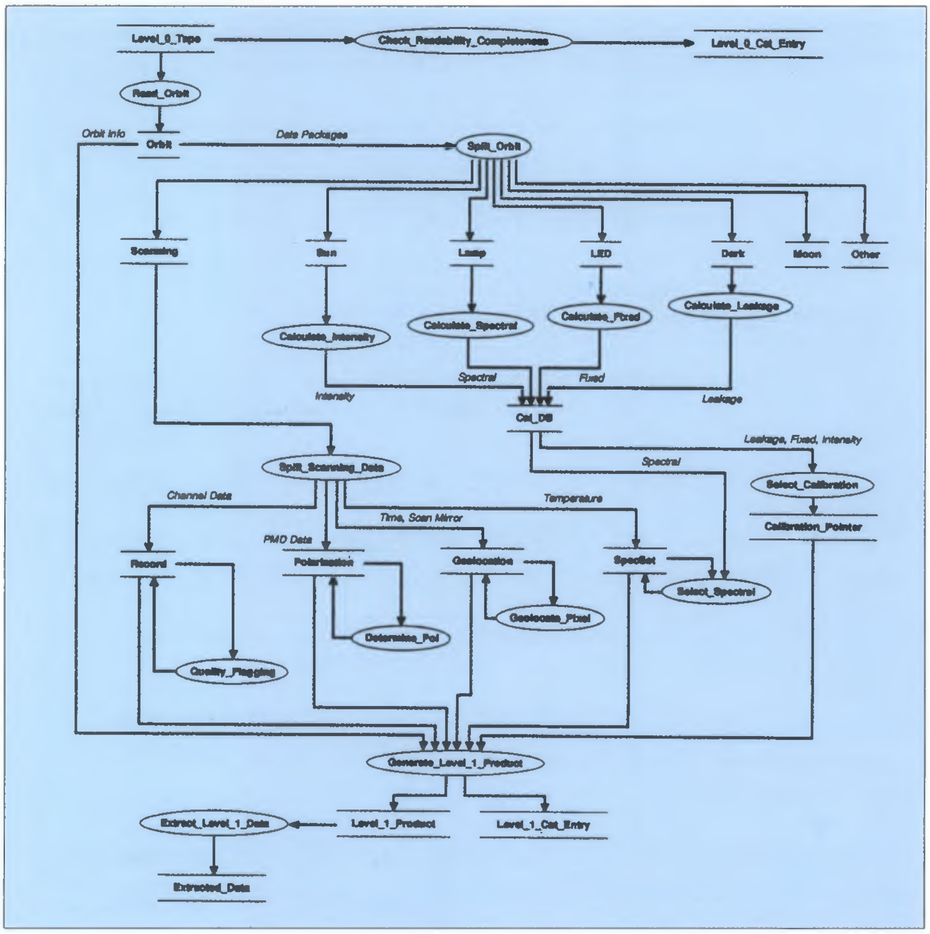


Figure 9.4-1 Level 0 to 1 processing functional model diagram

The major results of Level 0 to 1 processing are the Level 1 Data Products. The following requirements were the driving factors for the design of a Level 1 Data Product format:

- storage space should be saved in the archive and on distribution media;
- most of the information included in Level 0 Data should be retained in the Level 1 Data Product (reversibility of processing);
- error values should be given on the earthshine spectrum and the sun reference spectrum.

These requirements imply a format as given in the Interface Specification Document [Appendix B], in which no calibration data are actually applied to the raw spectrum data. To get Level 1 Data (which might be used for further Level 1 to 2 processing), an additional processing step (for extracting these data from the Level 1 Data Product) is performed to apply the calibration data to the signal data, and to calculate the associated errors.

Figure 9.4-1 shows a functional model diagram for the Level 0 to 1 processing, including the main functions and the internal and external data stores.

The main functions of the GDP Level 0 to 1 software are:

Screening of Level 0 Data

- Check readability and completeness

Level 0 to 1 Processing Initialisation

- Read an orbit from tape; this function has the following sub-functions
  - Check consistency and plausibility of each data package
  - Convert from binary units into "engineering units"
- Split into different types of data packages
- Split scanning data packages into channel data, PMD data, time & scan mirror position and temperature.

Calculation of Calibration Parameters

- Calculation of the leakage current correction
- Calculation of the fixed pattern correction
- Calculation of the spectral calibration parameters
- Calculation of the intensity calibration parameters

Selection of Calibration Parameters

- Selection of fixed calibration parameters for one orbit (Leakage, LED, Intensity)
- Selection of spectral calibration parameters for each temperature (predisperser prism)

Scanning Data Calculations

- Geo-location of the ground pixels
- Determination of the polarisation correction
- Assessment of scanning data quality and flag setting

Generation of Level 1 Output Data

- Generation of the Level 1 Data product
- Extraction of the Level 1 extraction data; application of calibration parameters and calculation of the associated errors are performed:

  - Application of the leakage current correction
  - Application of the LED fixed pattern
  - Application of the spectral calibration parameters
  - Application of the intensity calibration parameters
  - Application of the polarisation correction
  - Application of the stray light correction
  - Calculation of measurement errors

The main processing logic of the Level 0 to 1 processing is straight-forward. Screening is done once for a Level 0 Tape. After that, there is only one main loop. Within that loop, the complete Level 0 to 1 processing for one orbit is performed. This is repeated for every orbit which is on a Level 0 Tape until all orbits are processed. The last activity in each loop is the generation of Level 1 Data Products, which means that one process produces several Level 1 Data Products.

The extraction of Level 1 Data from a Level 1 Data Product, as included in the functional model, is not part of this process. This function may be executed using a different process to apply the calibration parameters to the signal data, to calculate the errors on the signals and to print this information in a more convenient form. This programme will be part of each Level 1 Data Product in executable (SunOS and MS-DOS) and source codes, and will be used as the Level 1 Data interface function for Level 1 to 2 processing.

A description of all the various fields and their meanings is given in the GOME Data Product Definition Document, Appendix C.

9.5 Level 1 -> 2 Processing

From the calibrated spectra as generated in the Level 0 to 1 processing, the total ozone column amount is retrieved by means of the DOAS technique. The scientific background of this technique is described in /6/. The result of the DOAS retrieval is a total column amount of the species under consideration (e.g., O_3, NO_2, ClO , BrO , etc.) **along the viewing direction of the instrument** at the time of spectrum recording ("slant column").

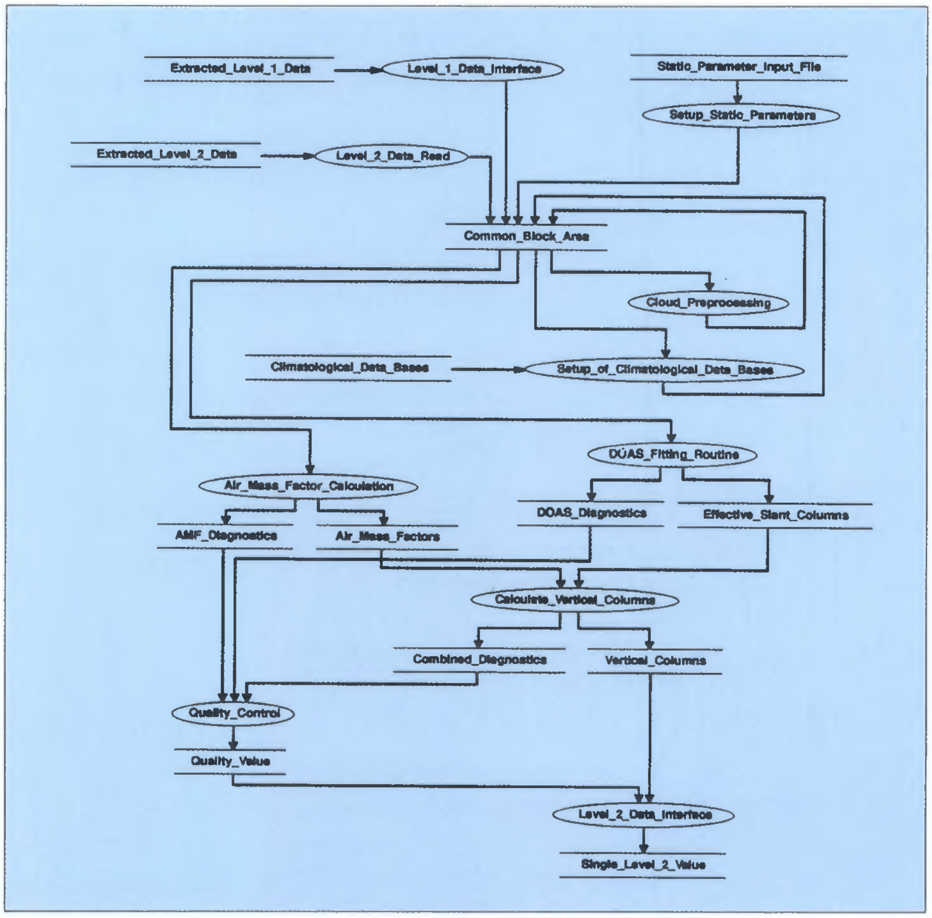


Figure 9.5-1 Functional processes and data stores required for Level 1 to 2 operational processing software

The conversion to a vertical column is achieved by applying the so-called Air Mass Factor (AMF) which not only takes into account geometrical relationships but also radiative transfer information. Because clouds affect the radiative transfer, it is necessary to detect them and take them into account in the processing.

Figure 9.5-1 illustrates the functional processes and data stores required for the first version of the Level 1 to 2 operational processing software.

One of the advantages of the DOAS approach to total column retrieval is that the spectral fitting (DOAS) and the radiative transfer (AMF) parts of the retrieval process are almost completely separate. The two main retrieval algorithms (labelled *DOAS_Fitting_Routine* and *Air_Mass_Factor_Calculation* in Figure 9.5-1) produce separate results and diagnostics.

Results from the two algorithms are combined in the process labelled *Calculate_ Vertical_ Columns*, while the diagnostics from the two algorithms are examined in the function labelled *Quality_Control.* The *Vertical_Columns* function will produce results (the total Ozone retrieved vertical columns) to be interfaced (written to) the final output file; it also produces a third set of diagnostics to be passed to *Quality_Control.* Once a quality value has been assigned to the results, this, too, can be written to the output Level 2 Data values.

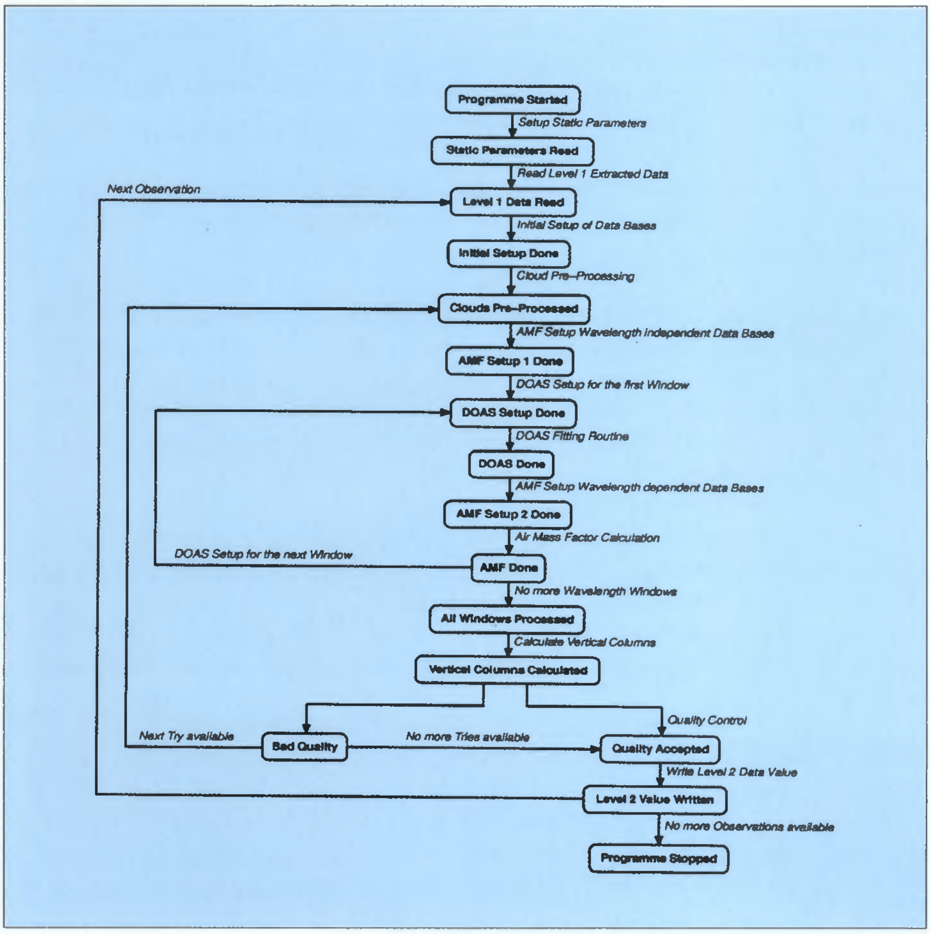


Figure 9.5-2 Dynamic Model Diagram

The upper part of the functional diagram is concerned exclusively with the setting up of correct variables for the two main algorithms mentioned in the previous paragraph.

The *Cloud_Preprocessing* function is a fitting routine designed to produce two important variables to be used in later algorithms - cloud top height and fractional cloud cover.

The final input function is the *Setup_Climatological_Databases*, in which information is extracted (and sometimes interpolated) from a bank of climatological data bases, according to the requirements of the three processing algorithms. A summary of the essential databases follows.

The main functions of the GDP Level 1 to 2 Software are:

- two main processing algorithms (AMF and DOAS fitting)
- one subsidiary algorithm (cloud pre-processing)
- four interface functions to Input/Output files (Static Parameters (I), Extracted Level 1 Data (I), Extracted Level 2 Data (I), Output Level 2 Data (O))
- two functions (*Vertical_Columns* and *Quality_Control) to process the results from the main algorithms*
- one function to extract and interpret data from Climatological Databases.

The functional model diagram says little about the processing logic and ordering of the functions and their components. For the GDP Level 1 to 2 operational software chain, this task can be summarised in the form of a dynamic model diagram. (Figure 9.5-2 shows a dynamic model diagram of the software chain.) In this model, the boxes represent states achieved in the programme, and the operations required to produce these states are printed in open italic form adjacent to the arrows which represent the state transition.

The first two dynamic operations are the input read functions. The function *Setup_Climatological_Databases* mentioned above is, in the dynamic model perspective, now divided into four separate operations. The four states achieved by these operations are the boxes <Initial Climatological Set-up Done>, <AMF Set-up 1 Done>, <AMF Set-up 2 Done>, and <DOAS Set-up Done>; the corresponding operations are marked in italics above these boxes.

The other dynamic operations in Figure 9.5-2 (*Quality_Control, Calculate_ Vertical_Columns, Write_Level_2_Data_ Value, Cloud_Pre-processing, DOAS_Fitting_Routine, Air_Mass_Factor_Calculation*) all correspond to their functional equivalents in Figure 9.5-1. The main point to observe in the dynamic model breakdown is the ordering of the operations and states, and the appearance of three main control loops.

For the first (inner) loop, all operations within that loop are repeated for each of the DOAS fitting windows selected for the operational processing. (The number of windows is a static parameter.) Inside this loop, the AMF calculation always follows the DOAS fitting; each algorithm is immediately preceded by a set-up routine. The final operations (*Vertical_Column, Quality_Control* and *Level_2_Data_Interface*) are not performed until the inner loop over fitting windows has been completed.

Execution of the middle loop depends upon quality control assessment, and the number of times this loop is executed depends upon the number of times one is willing to do the re-processing to obtain the best results; in practice, this will be severely limited by run-time considerations. Two remarks are in order here:

(1) It should be noted that re-processing does not automatically mean that both main algorithms will be repeated. In practice, it is likely that the DOAS fitting would **not** be repeated, whereas the AMF calculation(s) would be run again with different (better) climatologies, the improved choice of climatology depending upon the internal quality control assessment.

(2) Cloud information is not re-processed as a result of this internal Level 2 quality control evaluation. All cloud information is assumed to have passed its own independent quality control assessment before the main algorithms are embarked on.

For a given Level 1 Data Product (one orbit of data), the GDP Level 1 to 2 Dispatcher distributes batches of observations to several parallel processors. The processing of one such batch, which might be only one observation, is called a Level 1 to 2 **Process**. The Extracted Level 1 Data file for this Process contains scores of observations; the exact number of observations is read in the first line of header information. The chain from input to *Single_Value_Level_2* must be repeated for each observation; an exception is that the *Extracted_Data* files and the *Static_Parameter_Input* file (the latter independent of data!) do not need to be read for each observation, hence, the positioning of the outer "observation loop" in the dynamic diagram.

The dynamic system design includes the following decisions:

(i) The dynamic ordering of the operations and states follows that outlined in Figure 9.5-2.

(ii) Within the loop over the number of fitting windows, the AMF calculation always follows the DOAS spectral fitting.

(iii) The assessment of quality control and the production of retrieval results is deferred until the loop over fitting windows has been completed.

(iv) Re-processing following quality control assessment always starts after the cloud pre-processing algorithm.

(v) The initial read of the Extracted Level 1 Data file and the *Static_Parameter_Input* file is performed only once for each Process.

The databases used in the various processing modules (climatological database, molecular absorption cross-sections, etc.), as well as details of the algorithms used, are described in /9/ and /10/.

9.6 User Interface and Services

Data products are dispatched to users in two ways:

- On CD-ROM. This is the default medium for users of Level 1 data because of the large data volume. Three days of Level 1 and 2 data fill one CD-ROM with 600 Mb capacity.

- By FTP, secured by a password. This is the method of dispatch of Level 2 data. (At a later stage, it might be decided to collect about three months of Level 2 data on one "summary" CR-ROM).

Three groups of users have been distinguished:

1. Calibration/validation users, who are served right from the beginning of the data acquisition;

2. Science Users. These users will be served after a certain validation level of the products has been achieved, which is hoped to be at the end of the commissioning phase, about six months after launch.

These two groups have been selected from proposals received in response to an "Announcement of Opportunity for the European Remote Sensing Satellites ERS-1 and ERS-2" in October 1993.

3. Other users. The conditions applying to other users are still open at present.

The main user interface is through ESA's European Space Research Institute (ESRIN) at Frascati, Italy (near Rome; see Figure 9.6-1). In addition to certain system management tasks (e.g., maintenance of the high level operations plan), ESRIN provides the following services:

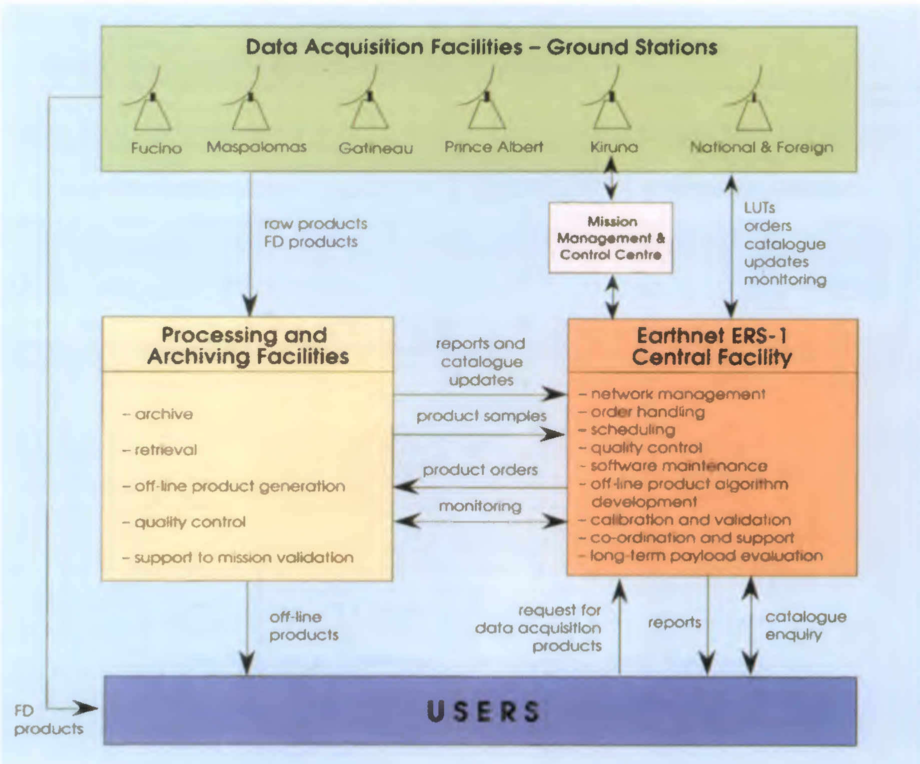


Figure 9.6-1 Functions and interactions of the "Earthnet ERS Central Facility"

Figure 9.6-2 European Space Research Institute (ESRIN) at Frascati, Italy

- a Help Desk for handling user inquiries; maintaining information on sensors, products, etc.
- order handling (see form in Appendix E)
- product catalogue: catalogue of all processed and archived data products accessible to the user
- product quality control
- long loop sensor performance monitoring

10. Concluding Remarks

10.1 GOME Data Validation

The launch of ERS-2 took place on 21 April 1995. Anticipated validation activities of the project team and of the more than 20 scientific groups world-wide supporting the GOME include:

Radiance/Irradiance

In fact, the true radiance and irradiance at the top of the atmosphere can be validated only with other spaceborne instruments. For the solar irradiance, the identified candidates expected to be still in-orbit at the time of the ERS-2 launch are:

- the SOLTICE instrument on UARS
- SSBUV on the Space Shuttle (if there is a coincident flight)

Because parameters such as spectral coverage, spectral resolution, Field-of-View, observation principles (direct or via diffusers), and orbital parameters are different for GOME on ERS-2, there is no direct one-to-one comparison possible. However, data from these instruments are supposed to provide a viable cross-comparison.

For the radiance, comparisons are possible with

- TOMS on Meteor
- SBUV-2 on NOAA satellites
- SSBUV on the Space Shuttle

Total Ozone Amount and Interfering Parameters

Satellite Data

Total ozone amount data products are produced by the following satellite-borne instruments:

- TOMS on Meteor
- SBUV/2 on NOAA satellites
- TOVS on NOAA satellites

Ground-Based Measurements

Various methods are used to measure total ozone amounts (and profiles, which then can be integrated) from the ground. The means selected for the GOME validation are:

- Dobson and Brewer instruments
- Ozone sondes
- Ozone lidar
- Microwave radiometer
- SAOZ (also for NO_2)

Some of these instruments (in particular, the DOBSON) are operated in more or less wide-spread networks.

Supporting Measurements

Next to the direct comparisons of parameters measured by GOME and other instruments, supporting data will be collected and archived: cloud information, temperature and pressure profiles, meteorological information, aerosol load, measurements of species other than those measured by GOME but possibly interacting with Ozone.

It is hoped that, by the end of the commissioning phase, confidence can be placed in the accuracy of the GOME data products, at least for relatively "standard" atmospheric conditions. However, when one realises the complexity of the "system under study" (the Earth's atmosphere as seen from space), one should be aware that a high level of accuracy can be achieved only in longer term observations involving several iterations on processing algorithms, operational procedures, database updates, etc.

10.2 Further Data Products

In addition to the "default" products as described in Chapters 9.4 and 9.5, other products derived from the GOME measurements might be generated. Some considerations, scientific studies, and implementation preparations are reported here briefly, without any commitment:

From Level 2 products, which include measurements of individual orbits, a re-sampling in time and space might lead to Level 3 products of **"monthly averaged global ozone"** and related trace gases, which are expected to be particularly suitable for climatological studies.

Much interest has been expressed by atmospheric scientists and meteorologists in **ozone profiles;** initial scientific studies indicate, in principle; the feasibility of developing these profiles. Issues such as vertical resolution and accuracy depend both on instrument performance and on the algorithm implementation. Implementation of these possible operations might be limited, however, by how efficiently radiative transfer computations can be performed; such computations are very demanding in terms of required computing power.

Finally, scientific studies and preparations for implementation are underway for a product which provides **aerosol** and **cloud** information, including cloud classification, at least for the more straight-forward cloud scenarios. This product will be derived from Level 1 products at the Italian PAF at Matera.

10.3 After GOME

The capabilities of GOME may be surpassed by the SCIAMACHY instrument, presently being developed for the ENVISAT project and scheduled to be launched at the turn of the century. Unlike the multi-national scope of GOME, SCIAMACHY is provided nationally by Germany and the Netherlands. So, even if there is a number of key requirements common to both instruments, there are significant differences in the practical implementation due to different project management and the industrial consortia involved arriving at different implementation solutions. Still, in principle, the mission of GOME is considered a subset of the SCIAMACHY mission. However, because it is more "project friendly" in terms of resource demands, accommodation, and finally cost, there is a possibility of flying a slightly improved GOME. Using the "lessons learned" from GOME on ERS-2, these instruments may be incorporated into the series of METOP satellites, presently under joint definition between ESA and EUMETSAT. Nominal performance of the GOME instrument and the supporting system will definitely increase the probability of a follow-on instrument generation for the next fifteen years.

10.4 Acknowledgements

It must be pointed out that the entire GOME programme was truly a team effort, involving many engineers, scientists, managers and supporting staff. Figure 10.4-1 outlines the industrial consortium which built and calibrated the flight hardware.

The Instrument Prime Contractor was **Officine Galileo, Florence (I)** with major contributions from **LABEN, Milan (I)** (DDHU and EGSE), **TPD-TNO, Delft (NL)** (Calibration Unit), and **Dornier, Friedrichshafen (D)** (Thermal Control Subsystem).

Under separate contracts, TPD-TNO performed instrument calibrations, and the **Rutherford Appleton Laboratories at Chilton (UK)**, with the support of **BAe, Bristol (UK)**, performed the necessary modifications to the ATSR-DEU.

Credit must also be given to the ERS-2 Prime Contractor, **Dornier, Friedrichshafen (D)** and the team of the AIT subcontractor **Fokker, Leiden (NL)** for their continuous support and flexibility in coping with the special needs of GOME.

With only a symbolic financial contribution from ESA, the **Deutsche Forschungsanstalt für Luft-und Raumfahrt (DLR), Oberpfaffenhofen (D),** developed the GOME Data Processor with funding from the **German Space Agency, DARA**.

Behind the names of these companies and institutions are the people who do the job. Out of the vast number of people who have supported GOME, naturally only a few key contributors can be mentioned; but this does not diminish the significant contributions made by those not mentioned.

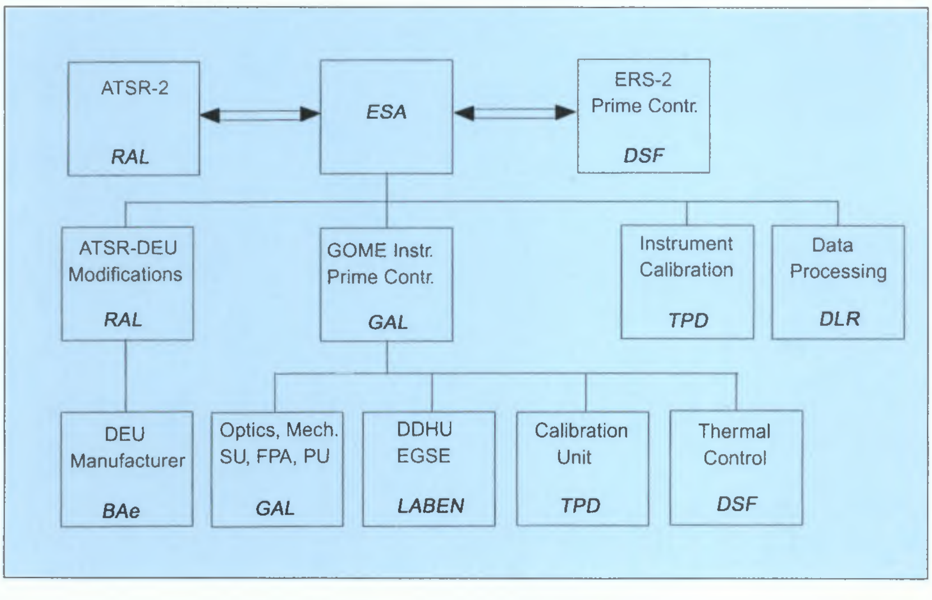


Figure 10.4-1 Industrial consortium for GOME

At Officine Galileo, the major contributions came from: **A. Mariani, R. Veratti, E. Corpaccioli, M. Fibbi, C. Cattarulla** and **G. Morelli**. The LABEN team's chief contributors were: **G. Fuggetta, B. Garavelli** and **A. Ferrato**, and for the TPD team: **L. Fontijn.** These teams are already heading for new projects. This is also true for **T. Faust** of Dornier, while **T. Edwards** from RAL and **M. Fletcher** and **N. Wright** from BAe stick to their subject: they are building AATSR for ENVISAT.

Special thanks to the ERS-2 Project Manager **U. Minne** and the GOME interface manager **M. Haimerl** from the Dornier Project Team. At the time of writing, the TPD calibration team was still busy with data analysis and post processing: **R. Hoekstra, C. Olij, E. Zoutman, M. de Cluse, A. Bos, G. Nützel** and **H. Verij.** Also busy with software coding and testing are the DLR team with **W. Balzer** and **R. Spurr**.

In addition to the engineering teams, the GOME project has enjoyed the continuous support of many scientists from all over Europe and the U.S., with **J. Burrows** from the Institut für Fernerkundung, Bremen (D), acting as the Lead Scientist. He has been supported by the members of the GOME Science Advisory Group, the subgroups for calibration, data processing and algorithm development and validation: **[U.S.A.]- K. Chance; [NL]- A. Goede, S. Slijkhuis, P. Stammes; [I]- R. Guzzi; [U.K.]- B. Kerridge, R. Munro; [D]- D. Perner, U. Platt, H. Frank, D. Diebel; [F]- J-P. Pommereau** and **[B]- P. Simon.**

All the various ESA establishments made their specific contributions to the GOME project: ESA Head Office, ESOC, ESRIN and ESTEC.

Finally, of the many staff members who helped in the realisation of GOME, the most significant contributors have naturally been the GOME "hard core" team: **A. Lefebvre, J. Callies,** and **B. Christensen,** with the active support of the entire ERS Project Division headed by **R. Zobl** and **P.G. Edwards.**

ANNEX A

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Note: * - References not available to the general public.
** - References available through the ESA Publications Division.

ANNEX B

List of Figures and Tables

ANNEX C

List of Acronyms

ADC	Analog-to-Digital Converter
AIV	Assembly, Integration, Verification
AMF	Air Mass Factor
AMI	Active Microwave Instrument
AOCS	Attitude and Orbit Control System
APM	Analog Processing Module
ATSR	Along Track Scanning Radiometer
BBM	Breadboard Model
BDDN	Broadband Digital Data Network
BRDF	Bidirectional Reflectance Distribution Function
CAT	Calibration Timeline
CU	Calibration Unit
CW	Command Word
DDDI	Double Differentiating, Double Integrating
DDHU	Detection and Data Handling Unit
DEU	Digital Electronics Unit
DMA	Direct Memory Access
DOAS	Differential Optical Absorption Spectroscopy
DSU	DEU Switching Unit
EEPROM	Electrically Erasable PROM
EMC	Electromagnetic Compatability
ERS	European Remote-Sensing Satellite
ESOC	European Space Operations Centre
ESRIN	European Space Research Institute
ESTEC	European Space Research and Technology Centre
FET	Field Effect Transistor
FIFO	First In, First Out
FM	Flight Model
FoV	Field of View
FPA	Focal Plane Assembly
FS	Flight Spare
GDP	GOME Data Processor
GMB	GOME Microprocessor Board
GOME	Global Ozone Monitoring Experiment
H/W	Hardware
HK	Housekeeping
I/F	Interface
I/O	Input/Output
ICU	Instrument Control Unit
IDHT	Instrument Data Handling and Transmission
IT	Integration Time
LED	Light Emitting Diode
LRDPF	Low Rate Data Processing Facility
LSB	Least Significant Bit
MCMD	Macrocommand
MLI	Multi-Layer Insulation
MMCC	Multi-Mission Control Centre
MPSTB	Mirror Position Strobe
MSB	Most Significant Bit
NIR	Near Infrared
NIST	National Institute of Standards and Technology
NOT	Normal Observation Timeline
NPOT	North Pole Observation Timeline
O/B	Optical Bench
OBC	Onboard Computer
OBDH	Onboard Data Handling
PAF	Processing and Archiving Facility
PCB	Printed Circuit Board
PCS	Power Control Service
PDU	Power Distribution Unit
PMD	Polarisation Monitoring Detector
PRARE	Precise Range and Range Rate Equipment
PRL	Pixel Readout Logic
PU	Polarisation Unit
QCM	Quartz Crystal Monitor
RA	Radar Altimeter
RAM	Random Access Memory
RTM	Remote Telemetry Module
S/W	Software
SAR	Synthetic Aperture Radar
SOL	Switch Off Line
SOT	Sun Observation Timeline
SPOT	South Pole Observation Timeline
SSM	Secondary Surface Mirror
SSYNC	Scan Synchronisation
SU	Scan Unit
SUEA	Scan Unit Electrical Assembly
SUMA	Scan Unit Mechanical Assembly
TB	Thermal Balance
TV	Thermal Vacuum
UV	Ultraviolet
VIS	Visible
YSM	Yaw-Steering Mode

Appendix A

Timelines

As explained in Chapter 8, the routine operations of GOME will be by timelines stored on-board and activated by ground command to the ATSR-DEU.

These timelines have been defined prior to launch on the basis of the FM results evaluation and LOWTRAN simulations of the radiative fluxes expected in the various situations, in particular as a function of solar zenith angles. The settings will be reviewed and, if necessary, updated during the commissioning phase.

The meaning of the different columns is as follows:

Mode: a general statement on what is done in this period (i.e., nadir scan, dark current). The actual complexity of the mode setting is not really reflected in this, but it gives a general impression of what the data are used for.

Time: indicative for the duration of each setting.

SZA Solar zenith angle. The SZA forms the starting reference for starting the timelines, as it determines the illumination conditions on the ground. For any given location on Earth, the SZA varies with the seasons, even for a sun-synchronous orbit.

Band 1A ...4 Integration time settings for the various bands/channels. Note that both bands of channel 2 are always at the same integration time; this is a consequence of modifying the split wavelength between channels 1 and 2 to reduce the effects of stray light.

# of CMDS Number of commands. For some settings, two commands are necessary. Maximum number of commands per timeline is limited to 30.

In the following, the timelines as defined for routine operations are given as:

Normal Observation Timeline (NOT): used for routine observations for 13 out of 14 orbits per day.

Sun Calibration Timeline (SOT): as NOT, but with a period of 120 sec. around SZA 90° inserted for sun calibration.

Polar Observation Timelines (NPOT and SPOT): in the polar regions (North and South, respectively, depending upon the season), a sideways swath is inserted, in order to have polar coverage.

Observation Timeline (CAT): to update, once a month, the calibration data base for the processing.

fig. 3.1: TL_NORM_OP (NOT)

mode	time *	SZA	band 1A	band 1B	band 2A+B	Band 3+4	# of
	(s)	(deg)	(s)	(s)	(s)	(s)	CMD's
	duration	SZA tag.	240-310 nm	310-312 nm	312-405 nm	400-790nm	
nadir scan	180	100	60 (3)**	60 (3)	60 (3)	60 (3)	2
"	180	85	60 (3)	6 (30)	6 (30)	6 (30)	2
"	2460	75	30 (82)	1.5 (1640)	1.5 (1640)	1.5 (1640)	2
		...					
"	180	75	60 (3)	6 (30)	6 (30)	6 (30)	2
"	180	85	60 (3)	60 (3)	60 (3)	60 (3)	2
dark curr.		100	scan mirror to dark current position				
"	1200		60 (20)	60	60	60	1
"	900		60 (15)	6 (300)	6 (300)	6	2
"	300		30 (10)	1.5 (200)	1.5 (200)	1.5	2
still available	450						
sum	6030						15

* given only for information. Exact duration has to be calculated on the basis of the info in column 3.

** the number in brackets states the number of valid readouts performed in this time interval

Remark: In this timeline still 7.5 min are available. They can be used for a additional dark current measurements or for health checks or for recovery actions of the scan unit (TBD).

Note: GOME itself will continue its operation in the last commanded mode until it receives a new command. The 450 sec of still available time in the timeline is used for dark current measurement with the last commanded integration times in case no new command is sent.

fig 3.3.1) TL_POL_OP (NPOT)

mode	time *	SZA	band 1A	band 1B	band 2A+B	Band 3+4	# of
	(s)	(deg)	(s)	(s)	(s)	(s)	CMD's
	duration		240-310 nm	310-312 nm	312-405 nm	400-790 nm	
n-pole scan	180	100	60 (3)**	60	60	60	2
nadir scan	180	85	60 (3)	6 (30)	6 (30)	6	2
	2460	75	30 (82)	1.5(1640)	1.5 (1640)	1.5	2
		...					
	180	75	60 (3)	6 (30)	6 (30)	6	2
	180	85	60 (3)	60	60	60	2
dark curr.	1200	100	60 (20)	60	60	60	1
	900		60 (15)	6 (150)	6 (150)	6	2
	300		30 (10)	1.5 (200)	1.5 (200)	1.5	2
still available	450						
sum	6030						15

** the number in brackets states the number of valid readouts preformed in this time interval

fig. 3.3.2) TL_POL_OP (SPOT)

mode	time *	SZA	band 1A	band 1B	band 2A+B	Band 3+4	# of
	(s)	(deg)	(s)	(s)	(s)	(s)	CMD's
	duration		240-310 nm	310-312 nm	312-405 nm	400-790 nm	
nadir scan	180	100	60 (3)**	60	60	60	2
	180	85	60 (3)	6 (30)	6 (30)	6	2
	2460	75	30 (82)	1.5 (1640)	1.5 (1640)	1.5	2
		...					
	180	75	60 (3)	6 (30)	6 (30)	6	2
s-pole scan	180	85	60 (3)	60	60	60	2
dark curr.	1200	100	60 (20)	60	60	60	1
	900		60 (15)	6 (150)	6 (150)	6	2
	300		30 (10)	1.5 (200)	1.5 (200)	1.5	2
still available	450						
sum	6030						15

* given only for information. Exact duration has to be calculated on the basis of the info in column 3.

fig 3.4) TL_WAVE_CAL (CAT) (last 3 orbits)

mode	time (s) duration	SZA (deg)	band 1A (s) 240-310nm	band 1B (s) 310-312 nm	band 2A+B (s) 312-405 nm	band 3 (s) 400-605nm	Band 4 (s) 590-790 nm	# of CMD's
wave cal	3180	100	30 (106)*	30	1.5 (2120)	0.1875 (2120)	0.09375 (2120)	2
dark cal	300		30 (10)	30	1.5 (200)	0.1875 (200)	0.09375 (200)	1
FPN	270		0.09375 (180)	0.09375	0.09375	0.09375	0.09375	2
FPN	270		0.1875 (180)	0.1875	0.1875	0.1875	0.1875	2
LED cal	270		0.09375 (180)	0.09375	0.09375	0.09375	0.09375	2
LED cal	270		1.5 (180)	1.5	1.5	1.5	1.5	2
dark cal	60		0.09375 (40)	0.09375	0.09375	0.09375	0.09375	1
dark cal	2460		2304 (1)	2304	600 (4)	72 (34)	72	2
diffus cal	2460		2304 (1)	2304	600 (4)	72 (34)	72	1
wave cal	600		30 (20)	30	1.5 (400)	0.1875 (400)	0.09375	2
dark cal	300		30	30	1.5	0.1875	0.09375	1
dark cal	2460		2304 (1)	2304	600 (4)	72 (34)	72 (34)	2
still available	5130							
sum	18090							20

Appendix B

Product Specification Document

of the

GOME Data Processor

Product Specification Document
of the
GOME Data Processor

ER–PS–DLR–GO–0016

Iss./Rev. 2/A

Deutsche Forschungsanstalt für Luft– und Raumfahrt
Deutsches Fernerkundungsdatenzentrum

September 11th, 1995

compiled by W. Balzer, DLR, WT–DA–BS,____________________Date__________

Distribution List

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Sum		9

Document Change Log

Rev.	Date	Section	Description of Change	approved by	Sign
1/A	30.09.94	all	Completely new		
2/A	11.09.95	all	minor corrections		
		appendix	product formats were moved from ISD to PSD		

Table of Contents

Appendix

1 Introduction

1.1 Purpose and Scope

At its meeting in June 1990, the ESA Council approved the satellite project which followed the first European Remote Sensing Satellite (ERS–1). This new satellite (ERS–2), is intended to provide data continuity between ERS–1 and the European polar platforms. Its launch was performed on April, 21st 1995.

In addition to the mission objectives of ERS–1, ERS–2 is intended to make a significant contribution to atmospheric chemistry. Thus, in addition to the instruments on ERS–1 (AMI, ATSR, RA, PRARE, etc.), it also carries the Global Ozone Monitoring Experiment (GOME). This instrument is intended to measure a range of atmospheric trace constituents both in the troposphere and in the stratosphere.

GOME is a nadir–viewing spectrometer which in its normal mode scans across–track in three steps. The field of view may be varied in size from 120 km x 40 km to 960 km x 40 km – a total of five options. The mode with the largest footprint will provide global coverage at the equator within 3 days.

GOME will demonstrate the feasibility of using the differential absorption technique (DOAS) to observe trace constituents including ozone. Existing nadir–viewing instruments such as SBUV exploit the fact that the height at which solar radiation is back–scattered by the atmosphere varies with wavelength. However, this approach depends on an accurate radiometric calibration.

Besides the on–line components at the ground stations and the Mission Management and Control Center (MMCC) the GOME Data Processor (GDP) system will be the operational off–line ground segment for GOME. It will incorporate a Level 0 to 1 processing chain, the complete GOME data archive, a DOAS O_3 total column retrieval process (Level 1 to 2), and an image processing chain for the generation of higher–level products.

The first issue of the present product specification document (PSD) was one of the primary results of the Architectural Design (AD) phase of the GDP project. It was distributed as part of the Critical Design Review Data Package (CDR–DP) to the participants of this review and to the members of the geophysical validation group selected from the AO proposals by ESA. By that time it just contained the description of the proposed data products. The detailed specification of the product formats was contained in the Interface Specification Document (ISD) [A1]. This separation required the distribution of two documents to those who wanted to work with GOME data products and most of the content of the ISD was for internal use only. Therefore, a re–structuring of the PSD/ISD documents was planned and is implemented by the present issue of the PSD which includes also the format specification of the products.

Besides the new structure also the content was changed, mainly the format description due to changes imposed by new or modified requirements on the GDP. At present the information in this PSD is somehow stabilising, hopefully there will be only minor changes required to its content.

One addition not a change to the PSD is already planned: due to the large interest on the GOME sun measurements on its own and because the sun reference spectra as part of the Level 1 data products do not include all the intermediate processing results it is envisaged to have a new data product on the GOME sun spectra. More details about this new product are discussed recently and will be published in the next issue of the PSD.

1.2 Acronyms and Abbreviations

A list of about all abbreviations and acronyms which are used throughout the specification is given below:

AD	Architectural Design
AMF	Air Mass Factor
AO	Announcement of Opportunity
BBM	Bread Board Model
BDDN	Broadband Data Distribution Network
BSDF	Bi–directional Scattering Distribution Function
BU	Binary Units
CD–R	Compact Disc (Write Once, Read Multiple)
CEOS	Committee on Earth Observation Satellites
CDR–DP	Critical Design Review Data Package
DFD	Deutsches Fernerkundungsdatenzentrum
DOAS	Differential Optical Absorption Spectroscopy
DSR	Data Set Record
EGOC	Extracted GOME Calibration Data
ERS	European Remote Sensing Satellite
ESA	European Space Agency
FTP	File Transfer Protocol
GDP	GOME Data Processor
GOME	Global Ozone Monitoring Experiment
ICFA	Initial Cloud Fitting Algorithm
ISD	Interface Specification Document
ISIS	Intelligentes Satellitenbildinformationsystem
MMCC	Mission Management Control Centre
MPH	Main Product Header
PMD	Polarisation Measurement Device
PSD	Product Specification Document
SBUV	Solar Backscatter Ultra–Violet
SPH	Specific Product Header
UTC	Universal Time Coordinated
VCD	Vertical Column Density

1.3 References and Documents

The following documents are referenced in this specification:

[A1] Interface Specification Document of the GDP, ER–IS–DLR–GO–0004, Issue 2, 11.9.95

[A2] GOME Level 0 to 1 Algorithms Description, ER–TN–DLR–GO–0022, Issue 3, 15.7.95

[A3] GOME Level 1 to 2 Algorithms Description, ER–TN–DLR–GO–0025, Issue 1, 30.9.94

[A4] EECF to PAF Interface Specifications, ER–IS–EPO–GE–0102, Issue 3.0, 29.1.90

[A5] GOME Science Packet Description, ER–TN–ESA–GO–0096, Issue 2, 29.8.1991

[A6] GOME Flight Spare Model Software F.5 Test Report, ER–TR–ESA–GO–0467, Issue 1 – draft, 7.8.95

The following documents are applicable for this specification:

[A7] System Requirements Document of the GOME Data Processing, ER–SR–DLR–GO–0020, Issue 1/B, 15.10.93

[A8] Functional Software Requirements of the GOME Data Processor (Level 1), ER–SR–DLR–GO–0008, Issue 1/B, 15.10.93

[A9] Functional Software Requirements of the GOME Data Processor (Level 2), ER–SR–DLR–GO–0009, Issue 1/B, 15.10.93

[A10] Architectural Design Document of the GDP, ER–AD–DLR–GO–0021, Issue 1, 11.4.94

[A11] Architectural Design Document of the GDP (Level 1), ER–AD–DLR–GO–0011, Issue 1, 11.4.94

[A12] Architectural Design Document of the GDP (Level 2), ER–AD–DLR–GO–0012, Issue 1, 11.4.94

[A13] ESA Software Engineering Standards, ESA PSS–05–0, Issue 2, Feb. 1991

[A14] LRDPF Re–Host – Interface Specification, RH–IC–SPT–SY–0001, Issue 1/2, 15.12.93

[A15] GOME Requirements Specification, ER–RS–ESA–GO–0001, Issue 1, 5.7.1991

[A16] GOME Command Description, ER–TN–ESA–GO–0171, Issue1, 10.9.91

1.4 Overview

The present document is divided into the following sections:

- Products Overview
  This section gives a short overview about the products of GDP
- Level 1 Data Product
  This section gives a detailed description of the Level 1 Data Product
- DOAS Total Column of Ozone Product
  This section gives a detailed description of DOAS Total Column of Ozone Product
- Detailed Product Formats
  This appendix gives a detailed bit–by–bit description of the specified products and their extraction formats

2 Products Overview

There are the following products which will be distributed to the users:

- A CD-R including the Level 1 data products of approximately 3 days (35 orbits) and the corresponding sun reference and Level 2 data set (the total column of ozone calculated with the DOAS algorithm) of this period;
- The GOME sun reference spectra sets available at the FTP-server of DFD (not yet available!).
- The Level 2 data products available at the FTP-server of DFD.

The CD-R will have the following directory structure:

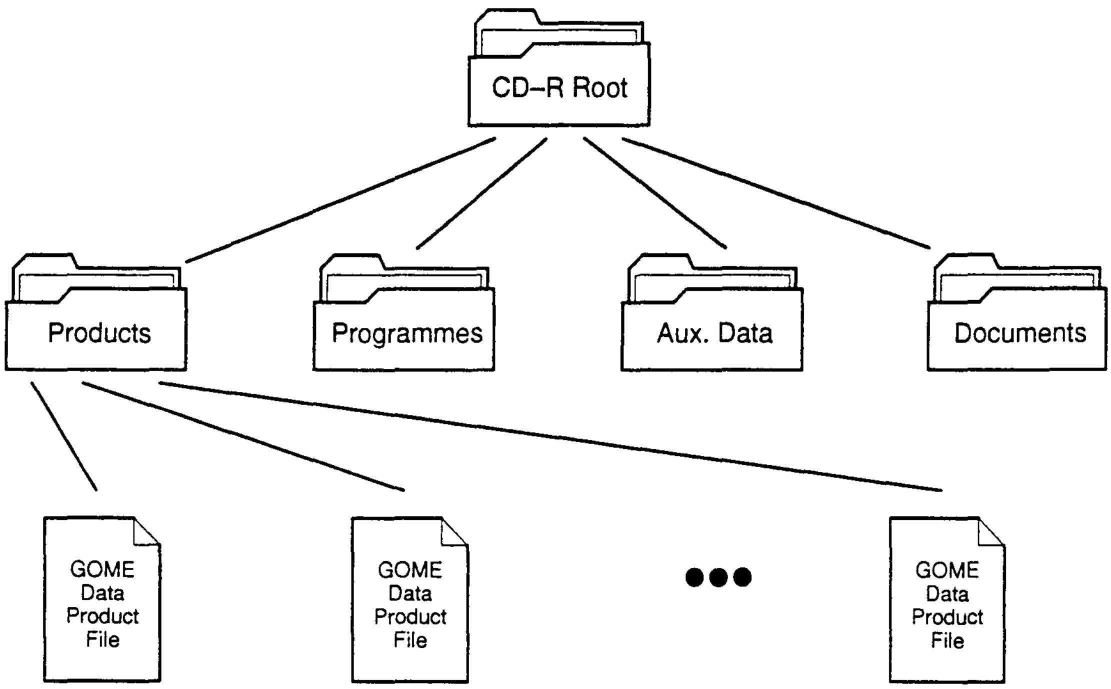


Figure 1: Distribution CD-R Content

The GOME data files which are included in the *Products* directory on the distribution CD-Rs are specified in section 3 for the Level 1 Data product and in section 4 for the Level 2 Data product. The specification for the sun reference product will be published later.

The *Programmes* directory will included at least the programmes to extract Level 1 data from the Level 1 data products and to extract Level 2 data products in ASCII representation. Other utilities for visualisation etc. are envisaged. The *Aux. Data* directory will included a copy of the Pre-flight Calibration Data Base version which was used for the Level 0 to 1 Processing and the climatological and spectroscopic data bases of the Level 1 to 2 processing. The *Documents* directory will include any type of documentation which is necessary at least to read and use the content of the CD-R (including a PostScript version of the present document).

The Level 2 Data and the sun reference products on the FTP-server being a part of the ISIS (Intelligentes Satellitenbild Informationssystem) of DFD will have the same format as the corresponding GOME data files on the CD-Rs. The directory hierarchy and the filenames will indicate the time period these data sets are covering. The filenames have been designed in a way to be usable under MS–DOS and are looking as follows:

```
99999999.lv2
|| | | |   |
|| | | |   +-- level of the product
|| | | +------ first digit of the minutes
|| | +-------- hour of the day
|| +---------- day of the month
|+------------ month of the year
+------------- last digit of the year
of the UTC start time of the product
```

E.g.: 50118015.lv2 (the Level 2 product from 18.1.95 01:5?).

Due to the large interest on the GOME sun measurements on its own and because the sun reference spectra as part of the Level 1 data products do not include all the intermediate processing results it is envisaged to have a new data product on the GOME sun spectra. More details about this new product are discussed recently and will be published in the next issue of the PSD. This product will be available on the FTP–server, but also copied to the CD–R together with the Level 1 data products.

3 Level 1 Data Product (LVL13)

3.1 Definition

The Level 1 Data product includes a header, fixed calibration data, ground pixel specific calibration parameters and ten spectral bands. With the different integration times, these bands (six spectrum bands, because channel 1 and 2 are divided into two electronically independent bands; three straylight bands; one blind band) are handled as separate logical units of data. The header includes reference to input data, processing software and pre–flight data versions, time correlation and orbital information. The fixed calibration data includes leakage current and noise characteristics, spectral and radiometric calibration parameters, sun reference spectra and polarisation sensitivity parameters. The pixel specific calibration parameters include geolocation information, seven fractional polarisation values and header information retained from the Level 0 Data. Using the included calibration data, the ADC readings of the diode arrays in the individual band data records may be converted to geolocated, spectrally and radiometrically calibrated radiances, including the correction for polarisation, leakage current and straylight. This may be accomplished by an extraction programme being part of a Level 1 Data product.

3.2 Description

Input

To generate GOME Level 1 Data products the following inputs are required:

- GOME extracted product files (EGOC) from Level 0 Tapes or send via BDDN, as described in [A1]. One EGOC product file (covering 1 orbit) is required to make up one Level 1 Data product.
- Restituted orbit information of the covered time period. The main product headers (MPH) of an extracted product file (EGOC) include state vectors of a predicted orbit. This orbit information may be used whenever the Restituted Orbit file of the requested period is not available. In this case the accuracies of the geolocation information and the sun reference spectrum are reduced.
- Pre–flight calibration data. *Conversion to Engineering Units*: Polynomial coefficients of analog data package measurements and other semantic explanations of the data package content; *Correction for Straylight*: Centre pixels of ghost columns, their efficiencies and defocussing; *Radiometric Calibration*: Bi–directional scattering distribution function of the diffuser in the calibration unit, Instrument response function, Polarisation characteristic of the calibration unit; *Polarisation Correction*: Polarisation sensitivity per pixel, Correction factor for the polarisation sensitivity per pixel to correct for the various scan mirror positions, Wavelength dependency of the PMDs, the PMD ratios.
- In–flight calibration data (Leakage current correction, Pixel–to–pixel gain information, Spectral calibration parameters, Sun reference spectra measurements).

Algorithms

The algorithms which are used to generate Level 1 Data products are listed below. A detailed description of these algorithms may be found in [A2].

- Conversion to Engineering Units
- Correction for Leakage Current and Determination of Noise
- Correction for pixel–to–pixel gain
- Correction for Straylight

- Spectral Calibration
- Radiometric Calibration
- Polarisation Correction
- Quality Flagging and Determination of Errors

Output

The extraction programme of the Level 1 Data product generates the following output:

- Geolocation Information
  - Date & Time
  - 3 Solar Zenith and Azimuth Angles (left, centre and right of ground pixel)
  - 3 Line–of–Sight Zenith and Azimuth Angles (left, centre and right of ground pixel)
  - Satellite Height and Earth Radius (Geoid)
  - 4 Corner Coordinates of Ground Pixel
  - Centre Coordinate of Ground Pixel
- PMD Data
- Spectrum Data
  - Wavelength
  - Earth–shine Radiance
  - Solar Irradiance
  - Associated Errors
  - Flags indicating quality of measurement

3.3 Specifications

Units

Angles	[degree]
Satellite Height and Earth Radius	[km]
Geographical Coordinates (long./lat.)	[0 – 360 degree/ (–90) – (+90) degree]
PMD Data	[photons m^{-2} nm^{-1} sr^{-1}]
Wavelength	[nm]
Radiance	[photons m^{-2} nm^{-1} sr^{-1}]
Irradiance	[photons m^{-2} nm^{-1}]
Errors	[absolute]

Geographical Coverage

Nominal: global

Depending on the scanning mode which will be used the measured ground pattern may be different. Only the largest footprint results in global coverage at the equator after three days. (see note below on spatial resolution)

Radiometric Resolution

16 Bit

Spectral Resolution

240 – 400 nm:	~0.2 nm
400 – 790 nm:	~0.4 nm

Spatial Resolution

Nominal: 3 ground pixels across–track with 40 km along–track, 320 km across–track

Depending on the scanning mode (swath width) the across–track range of one ground pixel may be: 320, 160, 120, 80 or 40 km.

Note: Due to the reduced integration time (1.5 sec to 0.375 sec) to avoid saturation on the detector arrays for the nominal mode only the last quarter of each ground pixel is covered by the recorded measurements. New sensor modes have been proposed and implemented on the GOME FS by ESA/ ESTEC to overcome this problem. These new modes are still tested and discussed by the members of the scientific advisory group. A detailed description of these modes is given in [A6].

Absolute Radiometric Accuracy

~ 3%

Relative Radiometric Accuracy

< 1%

Spectral Accuracy

0.01 – 0.02 detector elements corresponding 0.002 – 0.0045 nm

Spatial Accuracy

Restituted Orbit: 60 m along–track, 15 m across–track
Predicted Orbit: 920 m along–track, 15 m across–track (whenever the restituted orbit is not available)

Sizing

Level 1 Data will be calculated in granules of one orbit from an ascending node to the next. 35 orbits stored in 35 different files covering approximately a period of 3 days are logically packed to be one Level 1 Data product. Whenever the Level 2 Data product covering the same period is available, it will be also part of the Level 1 Data product.

3.4 Data Volume

~595 MB (35 Orbits per 17 MB) + ~35 MB (Level 2 Data) + ~5 MB (Programmes and documentation)

3.5 Presentation

The Level 1 data products will be available on CD–R. One part of these products will be the extraction programme to yield Level 1 extracted data. The format of the Level 1 data product and the extraction format is described in A.1 on page 18 and in A.3 on page 33, respectively.

3.6 Remarks

- *General*

The Level 1 Data product includes not directly the calibrated radiances, but the Level 0 Data values and the associated calibration parameters. This information has to be combined using a programme which is also part of the Level 1 Data product. The following requirements have driven the design of the Level 1 Data product format:

- Storage space should be saved in the archive and on distribution media;
- Most of the information included in the Level 0 Data should be retained in the Level 1 Data product;
- Error values should be given on the earth–shine and the sun reference spectrum.

These requirements imply a format as given in appendix A.1 where no calibration data is actually applied to the spectrum data. To get Level 1 Data which might be used for further processing, the additional data processing step for the *extraction* of this data from a Level 1 Data product must be carried out in order to perform the application of the calibration data to the signal data and to calculate the associated errors (see format in A.3).

- ***Variable Portions***

There are several places in the product where variable portions have been used to keep the product as compact as possible. This is always done by specifying the number of records prior to records themselves. The following places are found in the product:

- Pixel specific Calibration Records
- Band Data Records
- Input Data References
- State Vectors
- Hot Pixel Occurrences
- Spectral Calibration Parameters
- Sun Reference Measurements
- Polarisation Sensitivity Parameters
- Array Data Values

- ***Indexing***

To reduce redundant information and to increase flexibility in the reading of the product, an indexing scheme was used. The elements of some of the lists mentioned in the *Variable Portion* remark above are referred to by an index (number of the element in this list, starting with number 0) into other portions of the product. The following indices are used:

- From the Pixel specific Calibration Records into
  - the Band Data Records
  - the Spectral Calibration Parameters
  - the Polarisation Sensitivity Parameters
- From the Spectral Band Records into
  - the Pixel specific Calibration Records

This scheme allows the sequential read by time via the Pixel specific Calibration Records with indices to the available (depending on the integration time) spectral bands and the corresponding spectral calibration and polarisation sensitivity parameters. It also allows the sequential read of just one spectral band with indices to the Pixel specific Calibration Records which again give access to the necessary calibration data.

- ***Hot Pixels***

Individual detector pixels may be hit by high energy particles, such as protons. The worst situation could be permanent damage to the detector pixel; this case will be identified by a zero value in the pixel–to–pixel gain array in the Fixed Calibration Data Record. Another possibility is a transient effect whereby a detector pixel shows several abnormal (most probably very high) readouts before returning to normal operation. Such an occurrence, the so–called "Hot Pixel", will be identified by the Level 0 to 1 Processing and entered in this list.

- ***Spectral Calibration Parameters***

Depending on the temperature of the optical bench, the dispersion of the pre–disperser prism is different resulting in different spectral properties on the detector arrays. Using the spectral calibration lamp of the calibration unit, a set of spectral calibration parameters will be calculated for each occurring temperature. Measurements with GOME BBM in the thermal–vacuum chamber at Galileo have shown that the maximum shift for a temperature difference of 60 °C (–20° to +40°) is below one detector pixel. To fulfil the ultimate scientific requirement for the spectral resolution of $^1/_{100}$th of a detector pixel, it is possible to round the temperature measurements to a $^1/_{10}$th of degree Celsius. Therefore, temperature steps of 0.1 °C will used for the spectral calibration parameters. Measurements with the ERS–2 payload in the thermal–vacuum chamber at ESTEC have shown an orbital temperature variation of about 1 °C. Therefore, about 10 sets of spectral calibration parameters are expected to be in one individual product.

There is one set of spectral calibration parameters which is valid for the sun reference measurements and their mean value. The Intensity Calibration Parameters and the Polarisation Sensitivity values are interpolated to this wavelength grid.

- ***Intensity Calibration Parameters***

The Intensity Calibration Parameters are the interpolated instrument response (radiance sensitivity) function for the four detector arrays. The radiance sensitivity is dependent on the scan mirror angle. Therefore, it is necessary to include for each scan mirror angle occurring during time period of the product an array of radiance sensitivity values. For a nominal timeline three scan mirror angles are expected; a polar view timeline will yield in six different scan mirror angles.

- ***Sun Reference Spectrum***

The Sun Reference Spectrum is given in form of the individual sun calibration measurements (in BU), the mean value of these measurements using the Bi–directional Scattering Distribution Function (BSDF) of the diffuser and the mean values of the corresponding PMD measurements.

- ***Polarisation Sensitivity***

The polarisation sensitivity is also dependent on the scan mirror angle. Therefore, it is also necessary to include for each scan mirror angle occurring during time period of the product an array of polarisation sensitivity values.

- ***Level 0 Data Headers***

The Level 1 Data product will be the lowest level of GOME data which will be delivered to a general user. Therefore, it is a good idea to retain as much information as possible of the raw data. The following information of the Level 0 Data is copied into the Level 1 Data product:

- parts of the Main Product Header (MPH)
  - Product Confidence Data
  - UTC time when MPH was generated
  - Processor software version used to generate Level 0 Data product.
- parts of the Specific Product Header (SPH)
  - Product Confidence Data or Padding Flag
    (padding of the product DSR occurs in the event of missing frames containing GOME science data. The corresponding fields of the DSR are padded with BB hexadecimal)

  - Product Confidence Data
- parts of the Data Set Record (DSR)
  - Primary Header
  - Secondary Header
  - Auxiliary Data of the Science Data Packets

4 DOAS Total Column of Ozone Product

4.1 Definition

The GOME Level 2 data product comprises the product header, the Level 2 total ozone column amounts and their associated errors, selected geolocation information, and intermediate output. The latter will contain total column amounts of all retrieved trace gases, plus selected results and diagnostics from the GDP Level 1 to 2 algorithms, and a small amount of statistical information.

The Level 2 data product represents a compromise between compactness and usefulness – it must emphasize the total ozone column, and yet contain enough diagnostic information for validation and analysis. At the same time it must have the flexibility to allow for other trace gas retrieved columns. It is not feasible to output any detailed spectral information at Level 2.

4.2 Description

Input

The product defined here is the end result of the operational GDP Level 1 to 2 processing scheme. This processing requires the following inputs:

- One Extracted Level 1 data product, comprising
  - Geolocation information
  - Earth–shine radiance values and their absolute errors at specified wavelengths
  - Solar irradiance values and their absolute errors at specified wavelengths
  - Relative errors of the instrument response function
  - PMD data
- Climatological database, comprising
  - Trace gas concentration profiles, temperature and pressure profiles
  - Aerosol loading profiles, aerosol scattering properties
  - Global Surface albedo data set, sea surface albedo data set
  - Global topography data set
  - Cloud–top reflectance data set
  - Trace gas cross–sections data set; other reference spectra
  - GOME slit functions data set
- Input parameter file, comprising
  - DOAS fitting specifications (windows, reference spectra, fitting control,etc..)
  - Parameters controlling execution of Air Mass Factor algorithm
  - Parameters controlling cloud fitting algorithm
  - Overall control of the Level 1 to 2 processing chain

Algorithms

The algorithms to generate Level 2 data products are listed below. A detailed description of these algorithms may be found in technical note [A3].

- DOAS – spectral fitting for generation of slant column amounts
- AMF – calculation of Air Mass Factors
- ICFA – fitting algorithm to generate cloud fractional cover
- VCD – computation of vertical column amounts from results of above 3 algorithms
- Computation of statistical information in Level 2 data product

Output

The GDP Level 1 to 2 processing chain generates the following Level 2 output:

- Product Header Information
  - Pointers to retrieved species (see not below)
- Geolocation Information (a subset of the Level 1 geolocation data)
  - Date & Time
  - Solar and Line–of–Sight Zeniths at centre of ground pixel
  - Ground Pixel location coordinates (centre, four corners)
- Main Result Output
  - Total ozone column amount (plus error)
- Intermediate output, comprising
  - Vertical column amounts for all retrieved trace gases (and relative errors)
  - Slant column amounts for retrieved species (and relative errors)
  - Air mass factors for retrieved species (to cloud–top and to ground)
  - Cloud–top pressure and cloud fractional cover (and errors)
  - DOAS diagnostic information (includes RMS, chi–square, etc..)
  - Statistical information (sub–pixel colour and contrast)

4.3 Specifications

Units

Angles	[degree]
Geographical Coordinates	[0 to 360 degrees, –90 to +90 degrees]
Total ozone column amount	Dobson Units [DU]
Other trace gas column amounts	$mol.cm^{-2}$
Pressure	millibars
Errors	relative values in %

Geographical Coverage

Nominal: global

Depending on the scanning mode which will be used the measured ground pattern may be different. Only the largest footprint results in global coverage at the equator after three days.

Spatial Resolution and Accuracy

Nominal: 3 ground pixels across–track with 40 km along–track, 320 km across–track

Depending on the scanning mode, the across–track range may be: 320, 160, 120, 80 or 40 km. The accuracy is 60 m along–track, 15 m across–track for the restituted orbit, and 920 m along–track, 15 m across–track for the predicted orbit.

See note on spatial resolution in section 3.3 on page 8.

Accuracy

GOME Level 2 data products must be validated. During the commissioning phase, attention will focus on the validation of total ozone column amounts. Experience with ground based (and other) DOAS applications suggests that the error on total Ozone column amounts should be less than 1%, and for NO_2 less than 10%.

It is worth noting again that in most circumstances, the ozone column error induced by uncertainty in the tropospheric cloud cover across a pixel scene will in general be small – the bulk of atmospheric ozone lies in the stratosphere.

Sizing

Level 2 data product are sized for one orbit.

4.4 Data Volume

One Level 2 data product will contain approximately 2200 individual Level 2 records (covering one orbit with 2200 pixel scenes). This makes up a total of about 950 kbytes.

4.5 Presentation

Primarily the Level 2 data products will be available on ftp server. In addition, the Level 2 data products will be available on CD–R, along with the Level 1 data products (if already processed) and associated software and documentation (see previous section). The format of the Level 2 data product and the ASCII extraction format is described in A.2 on page 27 and in A.4 on page 40, respectively.

4.6 Remarks

- ***Main Result Output***

As ozone is the top priority measurement, the retrieved column of O_3 has been specified and formatted separately in the Level 2 output. O_3 columns are specified in the traditional Dobson Units. Ozone columns can be retrieved from the UV window (currently 323–335 nm) or from the visible window (430–530 nm) – only the best fitted value will be taken. The best fitting window for the visible region is still under investigation.

The ozone column amount will be the *latest value only* – that is, if individual re–processing has been carried out as a result of quality control in the Level 1 to 2 algorithm, only the re–processed value will be retained in the product. This also applies to all intermediate results.

- ***Geolocation Output***

The geolocation output is a selection from the Level 1 data product. Level 1 and Level 2 data products are identically geolocated.

- ***Trace gas column retrievals***

The output of trace gas results other than those for O_3 is governed by the fact that both DOAS fitting windows are optimized for ozone column retrieval. This limitation rules out species such as ClO and NO_3 with no significant spectral signatures in these windows. Some species are marginal – only in a few circumstances could we expect to see reasonable values for SO_2 and HCHO for example. NO_2 and H_2O are the main interfering species, NO_2 for both the GOME operational windows, H_2O only for the visible window. BrO is sometimes an interfering species in the UV window.

Ozone is not singled out from other retrieved trace gas columns in the intermediate output. For the UV window then, we would expect retrieved columns of O_3, NO_2 and perhaps BrO to be derived from Level 1 to 2 processing, and O_3, NO_2 and H_2O columns should be retrieved routinely from the visible window. A flag in the product header will indicate which trace gas total column has been retrieved in which window. The following disclaimer is important.

Additional output for other trace gases should not at this stage be regarded as the last word – only ozone amounts will be verified thoroughly during the commissioning phase, and the other trace gas quantities should be regarded as research products.

- ***Intermediate Results Output***

The intermediate Level 2 results are be classified according to source of information (whether from the Level 1 to 2 algorithms [AMF, VCD, DOAS, ICFA], or from additional sources [statistical output]). The results are accompanied by a small number of flags – these will indicate which options have been used in the execution of the algorithms, and for the statistical output, the availability of data.

VCD algorithm
The VCD intermediate output will comprise up to 7 vertical column amounts (down to ground only) for all retrieved trace gases (including at the least, O_3 twice for the 2 windows, NO_2 twice, and H_2O for the visible window). [Main product result for ozone is duplicated, but it was thought best to retain all trace gas results on an equal basis in the intermediate record]. Also output will be the errors on these quantities (7 entries). The control flag will indicate whether individual re–processing was performed, and the method of calculation of the ghost vertical column (see [A14], chapter 5).

Not included are vertical columns down to the cloud–top (these can be derived from Air Mass Factor and slant column information), and the ghost climatological columns (requires knowledge of climatological trace gas profile information).

DOAS algorithm
The basic level 2 intermediate output from the DOAS algorithm will be the effective slant columns (ESCs) and their errors, for all retrieved trace gases (14 entries). Single number fitting diagnostics will be given in the product – these include the RMS value, the final chi–square value, number of iterations in the fitting, and the goodness–of–fit statistic (8 entries for the two windows). The flag indexing this DOAS information will indicate whether the linear or non–linear fitting has been applied (fixed *versus* varying shifts and squeezes), and a qualitative (good/bad) indication of the accuracy of the fitted shifts and squeezes. The flag will also indicate whether reference spectra such as the Ring spectrum were used in the fit.

Not included are the fitting parameters (and their errors) for the low–order polynomial modelling the broad–scale features of the optical density spectrum (aerosols, clouds, surface reflection). Also not included is the correlation matrix of cross–correlations among different trace gas species and fitted polynomial coefficients (broad scale part of the spectrum).

AMF algorithm
The AMF output will include the *averaged* Air Mass Factors for all retrieved trace gases, both down to cloud–top and to ground level (14 entries). [If AMFs are calculated for each of the 3 possible geolocation geometries across a single ground pixel, the average result will be specified]. Simulated *total* intensities down to cloud–top and ground will be generated for both windows, plus one measured intensity (interpolated to the representative wavelength at which the AMFs were found) for each window (6 additional entries). The flag could indicate model simulation control (multiple vs. single scattering, use of 3 geometries, etc.).

Not included are intensities (to cloud–top and ground) calculated *without* the trace gas of interest (these quantities form part of the definition of the AMF). Note that no climatological information will be specified.

ICFA algorithm
The main output here is the cloud fraction and its error, and the cloud–top pressure and its error (4

entries). The surface pressure will also be specified here. The flag indexing this output will indicate the quality of the fit, version number and defaults used. Total 6 entries. Output of most diagnostics from ICFA has been suppressed (no RMS value, no chi–square, correlation matrix, etc.).

Statistical output
These numbers provide additional qualitative information about the measurements. They are supplementary to the main output, and are not derived from any geophysical algorithms. Two quantities are of interest – the "pixel contrast" and the "pixel colour". Pixel contrast values are found by taking the mean and standard deviation of the PMD reflectances (back–scattered to direct sunlight ratios) (6 entries for the 3 PMD devices). Pixel colour is indicated by the 16 sub–pixel values of the ratio PMD3/PMD2. The pixel colour gradient is taken from a linear regression carried out on GOME channel 3 measurements over a certain wavelength range (1 entry – the linear gradient). A flag indexes the output (availability of data). Note that this is the first attempt to use the PMD data, albeit in a non–physical way. Total 23 entries.

- ***Summary Table of Intermediate Output***

	(source)	(description)
–	VCD	Total vertical column amounts to ground
	VCD	Errors on these total vertical columns
	VCD	Flag indexing output
–	DOAS	Slant columns
	DOAS	Errors on these slant columns
	DOAS	RMS, chi–square, goodness–of–fit, iteration number
	DOAS	Flag indexing output
–	AMF	Air Mass Factors to cloud–top and ground
	AMF	Total intensity (ground and cloud top)
	AMF	Measured intensity
	AMF	Flag indexing output
–	ICFA	Cloud fraction & cloud–top pressure plus errors
	ICFA	Surface pressure
	ICFA	Flag indexing output
–	Statistics	Pixel contrast (mean & standard dev., 3 PMDs)
	Statistics	Pixel colour (sub–pixel values)
	Statistics	Pixel colour gradient (Channel 3)
	Statistics	Flag indexing output

A Detailed Format Descriptions

A.1 Level 1 Data Product

The Level 1 Data product file will consist of the following basic elements:

Field Number	Number of Bytes	Data Type	Byte Position	Description
1	38	PIR	1–38	Product Identifier Record see table 3
2	78	FSR1	39–116	File Structure Record see table 2
3	ca. 210	SPH1	117–322	Specific Product Header see table 4
4	ca. 575,788	FCD	323–576,110	Fixed Calibration Data Record see table 5
5	Nrec*669 ca. 1,471,800	PCD	576,111–2,047,910	Pixel Specific Calibration Records see table 7
6	ca. 15,576,000	BDR	2,047,911–17,623,910	Band Data Records see table 8

Table 1: Level 1 Data Product Content

This yields an approximate size of ≈17 MB (16.81 MB for the assumptions as made below) for one Level 1 Data product which covers one complete orbit.

The File Structure Record (FSR1) structure is given in the following table:

Field Number	Number of Bytes	Data Type	Byte Position	Description
1	2	short	1–2	Number of SPH1 Records (always 1)
2	4	long	3–6	Length of SPH1 Record
3	2	short	7–8	Number of FCD Records (always 1)
4	4	long	9–12	Length of FCD Record
5	2	short	13–14	Number of PCD Records
6	4	long	15–18	Length of PCD Record
7	2	short	19–20	Number of Band 1a Data Records
8	4	long	21–24	Length of Band 1a Data Record
9	2	short	25–26	Number of Band 1b Data Records
10	4	long	27–30	Length of Band 1b Data Record
11	2	short	31–32	Number of Band 2a Data Records
12	4	long	33–36	Length of Band 2a Data Record
13	2	short	37–38	Number of Band 2b Data Records
14	4	long	39–42	Length of Band 2b Data Record
15	2	short	43–44	Number of Band 3 Data Records
16	4	long	45–48	Length of Band 3 Data Record
17	2	short	49–50	Number of Band 4 Data Records
18	4	long	51–54	Length of Band 4 Data Record
19	2	short	55–56	Number of Blind Pixel Data Records
20	4	long	57–60	Length of Blind Pixel Data Record
21	2	short	61–62	Number of Straylight 1a Data Records
22	4	long	63–66	Length of Straylight 1a Data Record
23	2	short	67–68	Number of Straylight 1b Data Records
24	4	long	69–72	Length of Straylight 1b Data Record
25	2	short	73–74	Number of Straylight 2a Data Records
26	4	long	75–78	Length of Straylight 2a Data Record

Table 2: File Structure Record Content

The Product Identifier Record (PIR) structure is given in the following table, as defined in [A4]:

Field Number	Number of Bytes	Data Type	Byte Position	Description
1	2	A	1–2	Satellite/Mission Identifier (`E2`)
2	3	A	3–5	Sensor Identifier (`GOM`)
3	5	A	6–10	Start Orbit Number (e.g. `05765`)
4	4	A	11–14	Number of Processed Orbits (e.g. `0001`)
5	2	A	15–16	Acquisition Facility Identifier (e.g. `KS`, if more than one station, this field is `DP`)
6	5	A	17–21	Product Type (`LVL10`)
7	1	A	22	Spare, blank
8	2	A	23–24	Processing Facility Identifier (`DP`)
9	8	A	25–32	Processing Date (`YYYYMMDD`)
10	6	A	33–38	Processing Time (`hhmmss`)

Table 3: Product Identifier Content

The Specific Product Header (SPH1) structure for the Level 1 Data product is given in the following table:

Field Number	Number of Bytes	Data Type	Byte Position	Description
1	2	short	1–2	Number of Input Data References (Nref=2)
2	38 * Nref= 76	PIR	1–78	Input Data Reference; see table 3 (Product Type field: LVL0_)
3	5	A	79–83	GDP Software Version, Level 0 to 1 Processing (XX.XX)
4	5	A	84–88	Pre–flight Calibration Data Version (XX.XX)
5	5 * 4 = 20	unsigned long	89–108	Time Correlation Information: – Orbit Number – UTC days since 1.1.1950 – UTC ms since midnight – Satellite Binary Counter – Satellite Binary Counter Period
6	2	short	109–110	GOME Science Package PMD Entry Point
7	2	short	111–112	GOME Science Package Subset Counter Entry Point
8	(2 * 3) * 4 = 24	float	113–136	PMD's Conversion Factors
8	2	short	137–138	Number of State Vectors (Nvec, ca. 2)
9	(3 * 4 + 6 * 4) * Nvec ca. 72	3 * unsigned long 6 * float	139–> ca. 210	State Vectors (Restituted Orbit): – UTC days since 1.1.1950 – UTC ms since midnight – Orbit number – Position vectors (X, Y, Z) in km – Velocity vector (dx/dt, dy/dt, dz/dt) in m/s

Table 4: Specific Product Header Content (Level 1)

The Fixed Calibration Data Record (FCD) structure is given in the following table:

Field Number	Number of Bytes	Data Type	Byte Position	Description
1	2	short	1–2	Detector Confidence Flags: Bit 16–12: always 0 Bit 11: PMD 3 Bit 10: PMD 2 Bit 9: PMD 1 Bit 8–7: Array 4 Bit 6–5: Array 3 Bit 4–3: Array 2 Bit 2–1: Array 1 0 = detector ok 1 = detector is dead 2 = detector has dead pixels (arrays only)
2	10 * 6 = 60	BCR	3–62	Band Configuration Record; see table 6: 6 Spectral Bands 1 Blind Pixel Band 3 Straylight Bands
3	(4*4) * 4 = 64	float	79–142	Relative Errors on the Pre-flight Measurements
4	4 * 4 = 16	float	143–158	Uniform straylight level
5	4*2 * (2*2 + 2*4) = 96	short – float	159–254	Symmetrical and asymmetrical ghosts characteristics
6	2	short	255–256	Number of Leakage Correction Parameter Sets (Nleak, ca. 5; Integration Time Pattern or Time Line variance during one orbit)
7	(5 + 4,096) *4 * Nleak = 82,020	float	257–82,276	Array Noise, 3 PMD Offsets, PMD Noise and Dark Current
8	4,096 * 4 = 16,384	float	82,277 98,660	Pixel-to-Pixel Gain
9	2	short	98,661–98,662	Number of Hot Pixel Occurrences during this Orbit (Nhot, e.g. 5, hopefully zero)
10	3 * 2 * Nhot ca. 30	short	98,663–98,692	Hot Pixel Occurrences: Record, Array, Pixel
11	2	short	98,693–98,694	Number of Spectral Calibration Parameter Sets (Nspec, ca. 10; temperature variance during one orbit is expected to be ca. 1° and the temperature is resoluted to 0.1°)

12	(5 * 4 + 4) * 8 * Nspec ca. 1,920	double	98,695–100,614	Spectral Calibration Parameters (4th order polynomial) and Average Pixel Deviation for each channel
13	2	short	100,615–100,616	Index into Spectral Calibration Parameters for the following Calibration Parameters (field 14, 15, 19 and 21)
14	4,096 * 4 = 16,384	float	100,617–117,000	Intensity Calibration Parameters (Interpolated Instrument Response Function)
15	4,096 * 4 = 16,384	float	117,001–133,384	Sun Reference Spectrum (Mean Value)
16	4,096 * 4 = 16,384	float	133,385–149,768	Relative Radiometric Precision of the Sun Reference Spectrum
17	3 * 4 = 12	float	149,769–149,780	PMD Mean Values of the Sun Reference Spectra
18	3 * 4 = 12	float	149,781–149,792	Wavelength of the PMD Mean Values of the Sun Reference Spectra
19	2 * 4 = 8	unsigned long	149,793–149,800	UTC Date & Time of the Sun Refererence Spectrum
20	2	short	149,801–149,802	Number of Sun Reference Spectrum Measurements used for the following mean value (Nsun; ca. 20, 30 s of 1.5 s)
21	4,096 * 4 * Nsun = 327,680	float	149,803–477,482	Sun Reference Spectrum Measurements
22	2	short	477,483–477,484	Number of different scan mirror angles per channel for which the pre–flight calibration parameters "Interpolated Polarisation Sensitivity" and "Radiance Response" are calculated (Nang; e.g. 12)
23	(1,024 + 1024) * 4 * Nang = 98,304	float	477,485–575,788	Interpolated Polarisation Sensitivity ($\eta_{nadir} \cdot \varkappa(\omega)$) defined in [A2] section "Polarisation Correction" and Radiance Response ($H(\lambda,\sigma)$) defined in [A2] section "Radiometric Calibration"

Table 5: Fixed Calibration Data Content

The Band Configuration Record (BCR) structure is given in the following table:

Field Number	Number of Bytes	Data Type	Byte Position	Description
1	2	short	1–2	Detector Array Number (1–4)
2	2	short	3–4	Start Detector of Band (0–1023)
3	2	short	5–6	End Detector of Band (0–1023)

Table 6: Fixed Calibration Data Content

The Pixel Specific Calibration Records (PCD) structure is given in the following table:

Field Number	Number of Bytes	Data Type	Byte Position	Description
1	97	GLR1	1–97	Geolocation Record, see table 9
2	2 * 4 = 8	float	98–105	Dark Current & Noise Correction Factor
3	2	short	106–107	Index to Spectral Calibration Parameters
4	2	short	108–109	Index to Leakage Correction Parameters
5	22 * 4 = 28	float	110–197	Polarisation Parameters (7 fractional polarisation values including the appropriate wavelength value, error and Chi, the angle of the plane of polarisation) defined in [A2] section "Polarisation Correction"
6	34	MPH: 6, 7, 16	198–231	Extraction of Level 0 Data MPH: fields 6, 7, 16; see [A1]
7	22	SPH: 5, 6 + 1 byte	232–253	Extraction of Level 0 Data SPH: fields 5, 6; see [A1] (last byte reserved to get field even)
8	396	IHR	254–649	Instrument Header Record of the Science Data Packet; see [A5]
9	10 * 2 = 20	short	650–669	Index to the 10 Spectral Bands –1, if the integration time of this band was not finished

Table 7: Pixel Specific Calibration Data Content

The Band Data Records (BDR) structure is given in the following table:

Field Number	Number of Bytes	Data Type	Byte Position	Description
1	284,900	REC	1–	Band 1a, Nlen=256, Iv=550 (see table 10)
2	2,182,400	REC	...	Band 1b, Nlen=493, Iv=2200
3	52,800	REC	...	Band 2a, Nlen=9, Iv=2200
4	3,436,400	REC	...	Band 2b, Nlen=778, Iv=2200
5	4,518,800	REC	...	Band 3, Nlen=1024, Iv=2200
6	4,518,800	REC	...	Band 4, Nlen=1024, Iv=2200
7	57,200	REC	...	Blind Pixel, Nlen=49, Iv=550
8	58,300	REC	...	Straylight Pixel 1a, Nlen=50, Iv=550
9	233,200	REC	...	Straylight Pixel 1b, Nlen=50, Iv=2200
10	233,200	REC	15,576,000	Straylight Pixel 2a, Nlen=50, Iv=2200

Table 8: Band Data Records Content

where the values for the number of pixels per spectral band (*Nlen*) are taken from table 5 field 2 (Band Configuration Record, *Nlen = End–Start + 1*) and the number of integration intervals (*Iv*) are estimates for one orbit to calculate the expected size of one Level 1 Data product.

The Geolocation Record (GLR1) structure is given in the following table:

Field Number	Number of Bytes	Data Type	Byte Position	Description
1	2 * 4 = 8	unsigned long	1–8	UTC Date & Time of the ground pixel
2	6 * 4 = 24	float	8–32	3 Solar Zenith and Azimuth Angles
3	6 * 4 = 24	float	33–56	3 Line–of–Sight Zenith and Azimuth Angles
4	4	float	57–60	Satellite Height
5	4	float	61–64	Earth Radius
6	1	char	65–65	Possible Sun–glint (0 = no, 1 = yes)
6	8 * 4 = 32	float	66–97	4 Corner Coordinates of Ground Pixel (Latitude and Longitude)

Table 9: Geolocation Record 1 Content

The Spectral Band Record (REC) structure is given in the following table:

Field Number	Number of Bytes	Data Type	Byte Position	Description
1	2	short	1–2	Quality Flags: Bit 8–7: Spectral check: $0 = \varepsilon < 0.02$ px $1 = 0.02 < \varepsilon < 0.05$ px $2 = \varepsilon > 0.05$ px Bit 6–5: Saturated pixels Bit 4–3: Hot pixels Bit 2–1: Dead pixels 0 = all pixels ok 1 = less than 1% of pixels affected 2 = more than 1% of pixels affected
2	2	short	3–4	Index to Polarisations Sensitivity Parameters
3	2	short	5–6	Index to Pixel Specific Calibration Parameters Record (PCD)
4	2	unsigned short	7–8	Integration Time (one count corresponds to 93.5 ms)
5	Nlen * 2 = ca. 2048	unsigned short	9–max. 2056	Array Data Values

Table 10: Spectral Band Record Content

A.2 Level 2 Data Product

The Level 2 Data product file will consist of the following basic elements :

Field Number	Number of Bytes	Data Type	Byte Position	Description
1	38	PIR	1–38	Product Identifier Record see table 3
2	12	FSR2	39–50	File Structure Record see table 12
3	ca. 118	SPH2	51–168	Specific Product Header see table 13
4	Nrec * 438 ca. 963,600	DDR	169– 963,768	DOAS Data Records see table 14

Table 11: Level 2 Data Product Content

This yields an approximate size of ~950 kB (941.18 kB for the assumptions as made below) for one Level 2 Data product which covers a one orbit of data.

The File Structure Record (FSR2) structure for the Level 2 Data product is given in the following table:

Field Number	Number of Bytes	Data Type	Byte Position	Description
1	2	short	1–2	Number of SPH2 Records (always 1)
2	4	long	3–6	Length of SPH2 Record
3	2	short	7–8	Number of DOAS Data Records (ca. 2200)
4	4	long	9–12	Length of DOAS Data Record

Table 12: File Structure Record (Level 2) Content

The Specific Product Header (SPH2) structure for the Level 2 Data product is given in the following table:

Field Number	Number of Bytes	Data Type	Byte Position	Description
1	38	PIR	1–38	Input Data References see table 3
2	5	A	39–43	GDP Software Version, DOAS Level 1 to 2, (XX.XX)
3	5	A	44–48	GDP Software Data Bases Version, (XX.XX)
4	2	short	49–50	Number of Fitting Windows (Nwin=3)
5	Nwin * 2 * 4 = 24	float	51–74	Window Pair (start and end wavelength in nm)
6	2	short	75–76	Number of Molecules (Nmol=7)
7	Nmol * (1 + 5) = 42	A	77–118	Molecule Pair (fitting window number and molecule name, e.g. 3NO2__

Table 13: Specific Product Header Content (Level 2)

The DOAS Data Record (DDR) structure is given in the following table:

Field Number	Number of Bytes	Data Type	Byte Position	Description
1	56	GLR2	1–56	Geolocation Record see table 15
2	4	float	57–60	Total Column of Ozone (Dobson Units)
3	4	float	61–64	Relative error on the Total Column (%)
4	374	IRR	65–438	Intermediate Results Record see table 16

Table 14: DOAS Data Record Content (Level 2)

The Geolocation Record (GLR2) structure is given in the following table:

Field Number	Number of Bytes	Data Type	Byte Position	Description
1	2 * 4 = 8	unsigned long	1–8	UTC Date & Time
2	4	float	9–12	Solar Zenith Angle of the Ground Pixel Centre
3	4	float	13–16	Line–of–Sight Zenith Angle of the Ground Pixel Centre
4	8 * 4 = 32	float	17–48	4 Corner Coordinates of Ground Pixel (Latitude and Longitude)
5	2 * 4 = 8	float	49–56	Center Coordinate of Ground Pixel

Table 15: Geolocation Record 2 Content

The Intermediate Results Record (IRR) structure is given in the following table:

Field Number	Number of Bytes	Data Type	Byte Position	Description
1	Nmol * 4 = 28	float	1–28	*VCD*: Total VCD to ground of e.g. O_3^{UV}, O_3^{VIS}, NO_2^{UV}, NO_2^{VIS}, BrO, H_2O, SO_2
2	Nmol * 4 = 28	float	29–56	*VCD*: Errors on VCDs above
3	2	short	57–58	*VCD*: Flag indexing output
4	Nmol * 4 = 28	float	59–86	*DOAS*: Slant Columns of e.g. O_3^{UV}, O_3^{VIS}, NO_2^{UV}, NO_2^{VIS}, H_2O, BrO, SO_2
5	Nmol * 4 = 28	float	87–114	*DOAS*: Errors on Slant Columns above
6	Nwin * 4 * 4 = 48	float	115–162	*DOAS*: RMS, χ^2, Goodness of Fit, Iteration Number for the Nwin fitting windows
7	2	short	163–164	*DOAS*: Flag indexing output
8	Nmol * 4 = 28	float	165–192	*AMF*: AMF to ground for species as listed above
9	Nmol * 4 = 28	float	193–220	*AMF*: AMF to cloud–top for species as listed above
10	Nwin * 4 = 12	float	221–232	*AMF*: Total intensities for ground for Nwin fitting windows †
11	Nwin * 4 = 12	float	233–244	*AMF*: Total intensities for cloud–top for Nwin fitting windows †
12	Nwin * 4 = 12	float	245–256	*AMF*: Measured Intensity for Nwin windows †
13	2	short	257–258	*AMF*: Flag indexing output
14	2 * 4 = 8	float	259–266	*ICFA*: Cloud fraction and Cloud–top Pressure
15	2 * 4 = 8	float	267–274	*ICFA*: Errors on Cloud fraction and Cloud–top Pressure
16	4	float	275–278	*ICFA*: Surface Pressure
17	2	short	279–280	*ICFA*: Flag indexing output
18	3 * 2 * 4 = 24	float	281–304	*Statistics*: Pixel contrast (3 PMDs: mean and standard deviation) ‡
19	16 * 4 = 64	float	305–368	*Statistics*: Pixel colour (sub–pixel values) ‡
20	4	float	369–372	*Statistics*: Pixel colour gradient (Ch. 3) ‡
21	2	short	373–374	*Statistics*: Flag indexing output

Table 16: Intermediate Results Record Content

* Note: Vertical Columns and Slant Columns are given in mol/cm^2
† Intensities returned as representative wavelenghts for the given windows (1 or 2 per window).

Absolute Radiance Units.
‡ For definitions, see section 4.6 on page 15.

The following tables define the flag indexing output of the different algorithms:
(bits will be set for underlined condition)

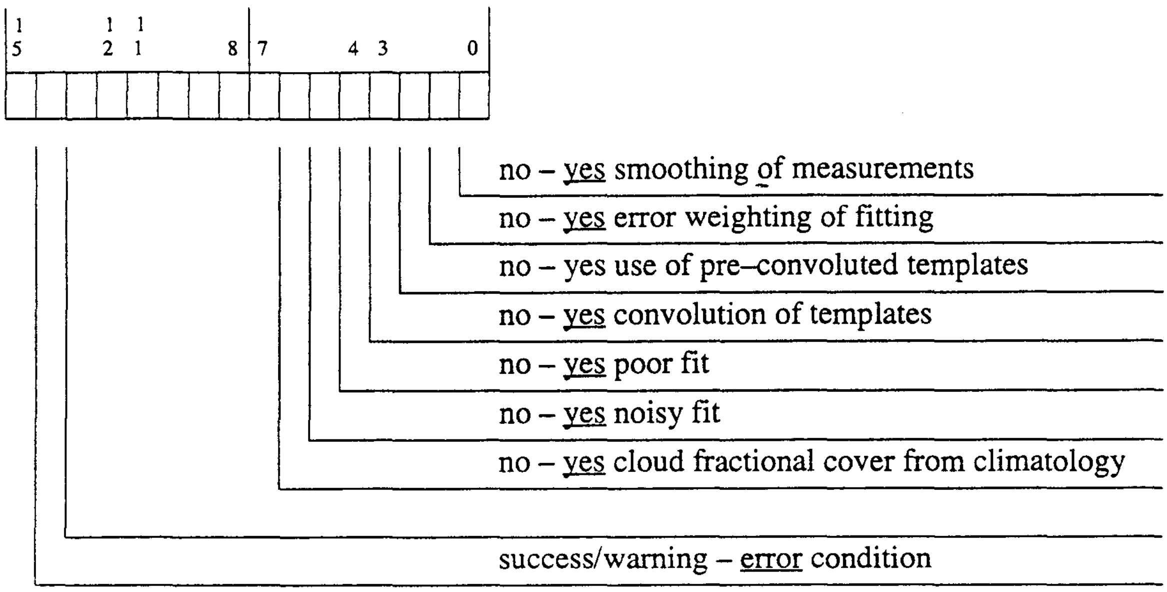


Table 17: ICFA Flag Indexing Output

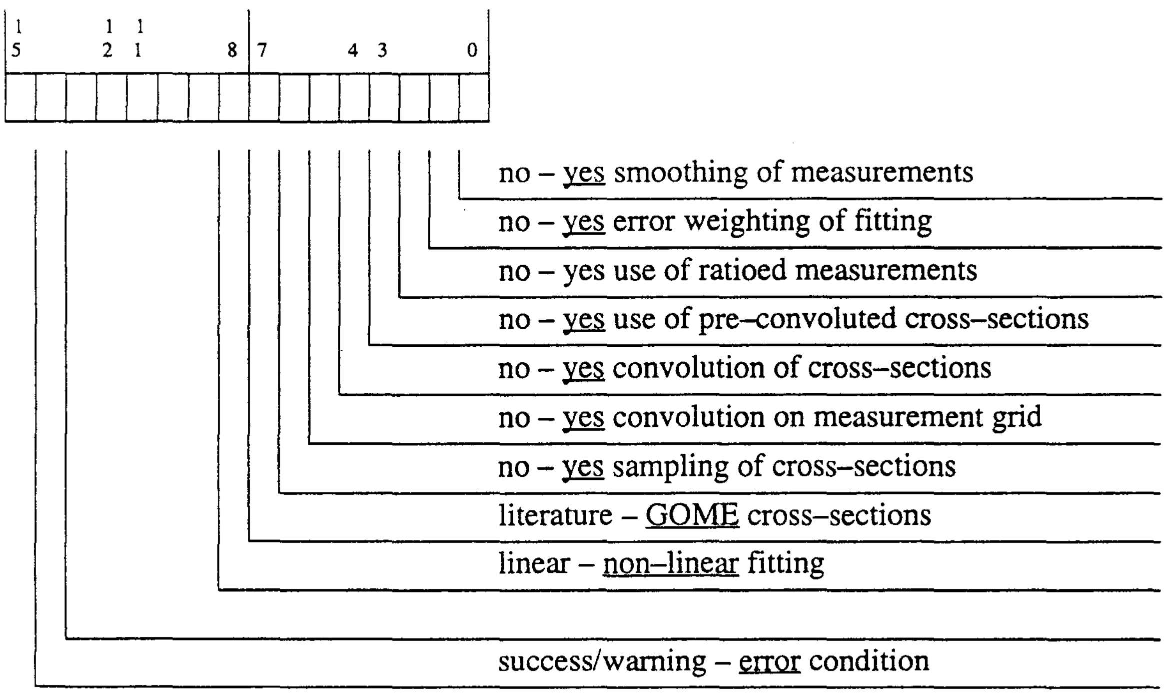


Table 18: DOAS Flag Indexing Output

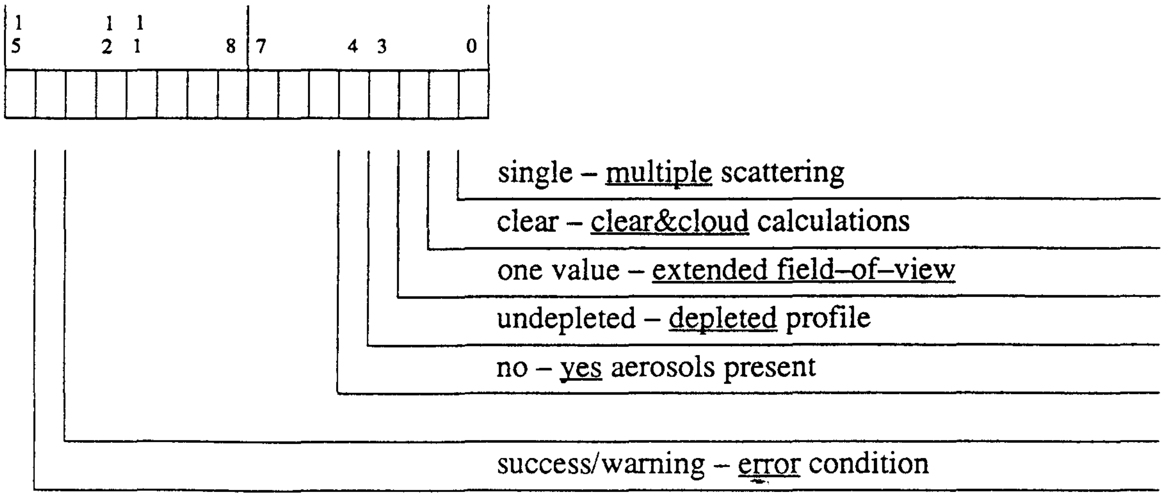


Table 19: AMF Flag Indexing Output

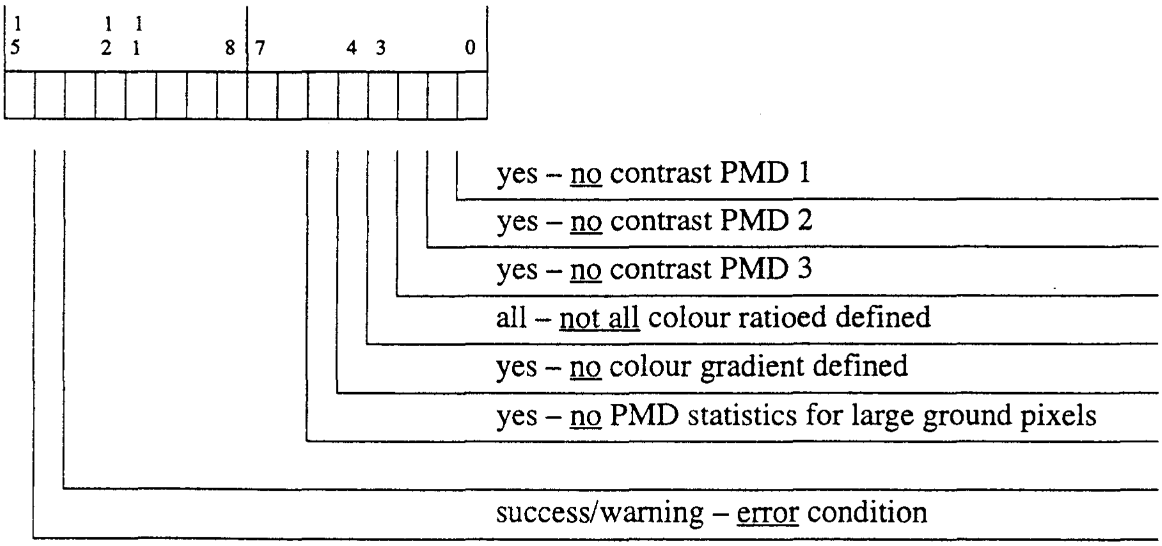


Table 20: Statistics Flag Indexing Output

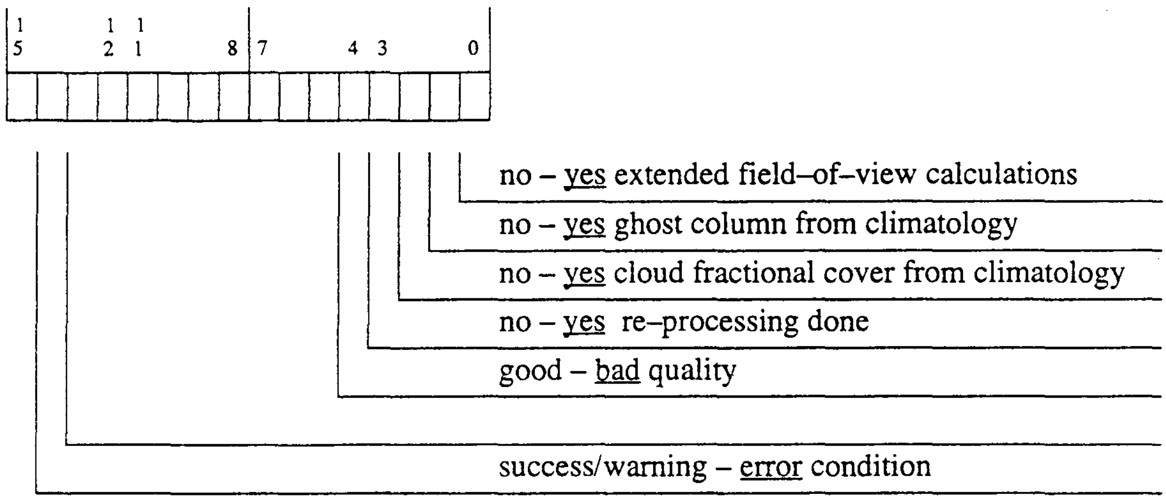


Table 21: VCD Flag Indexing Output

A.3 Extracted Level 1 Data

Extracted Level 1 Data files have the following format:

Field Number	Number of Bytes	Data Type	Byte Position	Description
1	328	GSI1	1–328	GDP Software Identifier, see table 23
2	38	PIR	329–366	Product Identifier, see table 3
3	1 or 2	char	367	Line Separator; the number of bytes for this field depends on the operating system the *Extract_Level_1_Data* programme was running on (e.g. UNIX = 1, MS–DOS = 2)
4	123 or 124	SFS	368–487	Solar Format Specification, see table 24
5	Nchannel * (47149 or 48169) = 188,596	CDR	488–189,083	Channel Data Records, (Nchannel = 4), see table 25
6	52 or 53	EFS	189,084–189,135	Earthshine Format Specification, see table 27
7	Nground * (189,447 or 193,527) = ~400 MB	EGP	189,136–	Earthshine Ground Pixels (Nground ca. 2200), see table 28

Table 22: Extracted Level 1 Data Content

The byte position information is given for the extraction of a complete Level 1 Data product. It is expected that for the normal case only parts (e.g. the wavelength windows for the DOAS fitting) are extracted which is much smaller than 400 MB.

The GDP Software Identifier (GSI1) structure for the Level 1 extraction software is given in the following table:

Field Number	Number of Bytes	Data Type	Byte Position	Description
1	80	A	1–80	Separator 1 (/*———————————————————*\)
2	1 or 2	A	81	Line Separator, see comment in table 22
3	80	A	82–161	Software Version (** GDP Level 0 to 1 Extracting – Version 9.99 – Copyright DLR 1995 **)
4	1 or 2	A	162	Line Separator, see comment in table 22
5	80	A	163–242	Separator 2 (*———————————————————*/)
6	1 or 2	A	243	Line Separator, see comment in table 22
7	35	A	244–278	Calibration Parameters Used (L:y, F:y, S:y, N:y, P:y, I:y, U:y,_)
8	1 or 2	A	279	Line Separator, see comment in table 22
8	48	A	280–327	Wavelength, Irradiance and Radiance Units (Units: [nm] [Photons/nm.cm^2.s] [Photons/nm.cm^2.s.sr])
8	1 or 2	A	328	Line Separator, see comment in table 22

Table 23: GDP Software Identifier

The Solar Format Specification (SFS) structure is given in the following table:

Field Number	Number of Bytes	Data Type	Byte Position	Description
1	15	A	1–15	Description (Solar_Spectrum_)
2	16	A	16–31	Wavelength Range [nm] (999.999_999.999_)
3	28	A	32–59	Average Pixel Deviation of the Spectral Calibration for each channel (9.9999_9.9999_9.9999_9.9999_)
4	12	A	60–71	UTC Date of Solar Spectrum (DD–MMM–YYYY_)
5	12	A	72–83	UTC Time of Solar Spectrum (HH:MM:SS.mmm)
6	1 or 2	char	123	Line Separator, see comment in table 22

Table 24: Solar Format Specification Content

The Channel Data Record (CDR) structure is given in the following table:

Field Number	Number of Bytes	Data Type	Byte Position	Description
1	10	A	1–10	Channel Identifier (Channel 9_)
3	16	A	11–26	Wavelength Range (nm) (999.999_999.999_)
4	8	A	27–34	Spectral Calibration Error (9.9999_)
5	2	A	35–36	Spectral check (9_) 0 = e < 0.02 px 1 = 0.02 < e < 0.05 px 2 = e > 0.05 px
6	2	A	37–38	Saturated pixels (9_) †
7	2	A	39–40	Hot pixels (9_) †
8	2	A	41–42	Dead pixels (9_) †
9	4	A	43–46	Number of Detector Pixels Samples (9999) (Nsamp)
10	1 or 2	A	47–48	Line Separator, see comment in table 22
11	Nsamp * (46 or 47)	SDR	49–47149 or 48169	Solar Data Records, see table 26 (e.g. Nsamp = 1024)

Table 25: Channel Data Record Content

† 0 = all pixels ok
1 = less than 1% of pixels affected
2 = more than 1% of pixels affected

The Solar Data Record (SDR) structure is given in the following table:

Field Number	Number of Bytes	Data Type	Byte Position	Description
1	8	A	1–8	Wavelength [nm], (999.999_)
2	12	A	9–20	Absolute Irradiance measurement [photons/nm.cm^2.s], (9.99999e–99_)
3	12	A	21–32	Absolute Irradiance measurement Error [photons/nm.cm^2.s], (9.99999e–99_)
4	12	A	33–44	Irradiance * relative response Error [photons/nm.cm^2.s], (9.99999e–99_)
5	1	A	45	Flag, (9) (e.g. 0=Good, 1=Dead, 2=Hot, 3=Saturated, ..., 9=other errors)
6	1 or 2	A	46	Line Separator, see comment in table 22

Table 26: Solar Data Record Content

The Earthshine Format Specification (EFS) structure is given in the following table:

Field Number	Number of Bytes	Data Type	Byte Position	Description
1	20	A	1–20	Description (Earthshine_Spectrum_)
2	26	A	21–46	Time Range (99:99:99_99:99:99_)
3	5	A	47–51	Number of Ground Pixels (9999) (Nground)
4	1 or 2	char	52	Line Separator, see comment in table 22

Table 27: Earthshine Format Specification Content

The Earthshine Ground Pixel (EGP) structure is given in the following table:

Field Number	Number of Bytes	Data Type	Byte Position	Description
1	18	A	1–18	Ground Pixel Number (Ground_Pixel_9999_)
2	2	A	19–20	Subset Counter (9_) ('0' to '2' forward, '3' backward)
4	1	A	21	Number of Band Data Samples (9) (Nband)
5	1 or 2	char	22	Line Separator, see comment in table 22
6	208 or 213	AGI	23–230	Geolocation Information in ASCII, see table 29
7	16 * (36 or 37)	PDR	231–806	PMD Data Values of the corresponding science data packet, see table 30
8	1 or 2	A	807	Line Separator, see comment in table 22
9	Nband * (47,160 or 48,180)	BDR	808–189,447 or 193,527	Band Data Records, see table 31 (e.g. Nband = 4)

Table 28: Earthshine Ground Pixel Content

The Geolocation Information in ASCII (AGI) structure is given in the following table:

Field Number	Number of Bytes	Data Type	Byte Position	Description
1	12	A	1–12	UTC Date of Ground Pixel Start (DD–MMM–YYYY_)
2	12	A	13–24	UTC Time of Ground Pixel Start (HH:MM:SS.mmm)
3	1 or 2	A	25	Line Separator, see comment in table 22
4	47	A	26–72	3 Solar Zenith and Azimuth Angles 3 * (–999.99_–999.99_)
5	1 or 2	A	73	Line Separator, see comment in table 22

6	47	A	74–120	3 Line–of–Sight Zenith and Azimuth Angles, 3 * (–999.99_–999.99_)
7	1 or 2	A	121	Line Separator, see comment in table 22
8	7	A	122–128	Satellite Height, (999.99_)
9	8	A	129–136	Earth Radius, (9999.99_)
10	1	A	137	Possible Sun–glint (9) 0 = no, 1 = yes
11	1 or 2	A	138	Line Separator, see comment in table 22
12	69	A	139–207	4 Corner and Center Coordinates, Lat. and Long., 5 * (–99.99_999.99_)
13	1 or 2	A	208 or 213	Line Separator, see comment in table 22

Table 29: Geolocation Information in ASCII Content

The PMD Data Record (PDR) structure is given in the following table:

Field Number	Number of Bytes	Data Type	Byte Position	Description
1	12	A	1–12	PMD 1 Data Value [photons/nm.cm^2.s.sr] (9.99999e–99_)
2	12	A	13–24	PMD 2 Data Value [photons/nm.cm^2.s.sr] (9.99999e–99_)
3	11	A	25–35	PMD 3 Data Value [photons/nm.cm^2.s.sr] (9.99999e–99)
4	1 or 2	A	36 or 37	Line Separator, see comment in table 22

Table 30: PMD Data Record Content

The Band Data Record (BDR) structure is given in the following table:

Field Number	Number of Bytes	Data Type	Byte Position	Description
1	8	A	1–8	Band Identifier (Band 9a_)
2	11	A	9–19	Integration Time [s] (9999.99999_)
3	16	A	20–35	Wavelength Range (nm) (999.999_999.999_)
4	8	A	36–43	Spectral Calibration Error (9.9999_)
5	2	A	44–45	Spectral check (9_) 0 = e < 0.02 px 1 = 0.02 < e < 0.05 px 2 = e > 0.05 px
6	2	A	46–47	Saturated pixels (9_) †
7	2	A	48–49	Hot pixels (9_) †
8	2	A	50–51	Dead pixels (9_) †
9	4	A	52–55	Number of Detector Pixels Samples (9999) (Nsamp)
10	1 or 2	A	56–56	Line Separator, see comment in table 22
11	Nsamp * (46 or 47)	EDR	57–47160 or 48180	Earthshine Data Records, see table 32 (e.g. Nsamp = 1024)

Table 31: Band Data Record Content

The Earthshine Data Record (EDR) structure is given in the following table:

Field Number	Number of Bytes	Data Type	Byte Position	Description
1	8	A	1–8	Wavelength [nm], (999.999_)
2	12	A	9–20	Absolute Radiance measurement [photons/nm.cm^2.s.sr], (9.99999e–99_)
3	12	A	21–32	Absolute Radiance measurement Error [photons/nm.cm^2.s.sr], (9.99999e–99_)
4	12	A	33–44	Radiance * relative response Error [photons/nm.cm^2.s.sr], (9.99999e–99_)
5	1	A	45	Flag, (9) (e.g. 0=Good, 1=Dead, 2=Hot, 3=Saturated, ..., 9=other errors)
6	1 or 2	A	46 or 47	Line Separator, see comment in table 22

Table 32: Earthshine Data Record Content

The following is an example for the specification of the extracted Level 1 Data, as described above (the text in brackets and the dots are only for information and shortness, not part of the data set):

```
/*--------------------------------------------------------------------------*\          (GSI)
**  GDP Level 0 to 1 Extracting  -  Version 3.02    -  Copyright DLR 1995     **
\*--------------------------------------------------------------------------*/
L:y, F:y, S:y, N:y, P:y, I:y, U:y
Units: [nm] [Photons/nm.cm^2.s] [Photons/nm.cm^2.s.sr]
E2GOM000000001KSEXTR1 DP19940506191143                                                 (PIR)
Solar Spectrum 19-MAY-1994 10:35:09.500                                                (SFS)
CHANNEL 1 236.898 314.484 0.0315 0 0 0 0 512                                           (SDR)
236.898 0.00000E+00 0.00000E+00 0.00000E+00 0
237.019 0.00000E+00 0.00000E+00 0.00000E+00 0
237.139 0.00000E+00 0.00000E+00 0.00000E+00 0
237.259 0.00000E+00 0.00000E+00 0.00000E+00 0
237.380 0.00000E+00 0.00000E+00 0.00000E+00 0
237.500 0.00000E+00 0.00000E+00 0.00000E+00 0
237.620 0.44720E+14 0.22360E+13 0.89441E+11 0
237.741 0.52373E+14 0.26186E+13 0.10475E+12 0
237.861 0.45247E+14 0.22623E+13 0.90494E+11 0
.....
790.000 0.50000E+15 0.30000E+14 0.20000E+13 0
Earthshine Spectrum 10:35:95.500 12:15:90.000 1500                                     (EFS)
Ground Pixel 1 0 2                                                                     (EGP)
20-MAY-1994 10:35:09.500                                                               (AGI)
 42.50 205.61  42.46 205.63  42.42 205.65
 10.00  90.00  19.68  90.00  -9.37 270.00
796.65 6361.36 0
-61.90 197.71 -62.23 197.98 -62.59 192.67 -62.93 192.89 -62.41 195.31
0.12345E+00 0.23456E+00 0.34567E+00                                                    (PDR)
0.12345E+00 0.23456E+00 0.34567E+00
0.12345E+00 0.23456E+00 0.34567E+00
0.12345E+00 0.23456E+00 0.34567E+00
0.12345E+00 0.23456E+00 0.34567E+00
.....
0.12345E+00 0.23456E+00 0.34567E+00
Band 1a 30 236.898 268.121 0.0493 0 0 0 0 255                                         (BDR)
236.898 0.00000E+00 0.00000E+00 0.00000E+00 0                                          (EDR)
237.019 0.00000E+00 0.00000E+00 0.00000E+00 0
237.139 0.00000E+00 0.00000E+00 0.00000E+00 0
237.259 0.00000E+00 0.00000E+00 0.00000E+00 0
237.380 0.00000E+00 0.00000E+00 0.00000E+00 0
237.500 0.00000E+00 0.00000E+00 0.00000E+00 0
237.620 0.44720E+12 0.22360E+11 0.89441E+09 0
237.741 0.52373E+12 0.26186E+11 0.10475E+10 0
....
268.121 0.95544E+13 0.47772E+12 0.19109E+11 0
Band 4 1.5 578.602 780.266 0.0331 0 0 0 0 1024                                         (BDR)
...
Ground Pixel 2 1 6                                                                     (EGP)
```

A.4 Extracted Level 2 Data

Extracted Level 2 Data files have the following format:

Field Number	Number of Bytes	Data Type	Byte Position	Description
1	328	GSI2	1–243	GDP Software Identifier in ASCII see table 34
2	38	PIR	244–281	Product Identifier Record see table 3
3	1 or 2	char	282	Line Separator; the number of bytes for this field depends on the operating system the *Extract_Level_2_Data* programme was running on (e.g. UNIX = 1, MS–DOS = 2)
4	4	A	283–286	Number of DOAS Data Records in ASCII (ca. 2200) (9999)
5	1 or 2	char	287	Line Separator, see comment in table 33
6	192	SPH2A	288–479	Specific Product Header in ASCII see table 35
7	N_DDR * 1373 = 2.059.500	DDRA	480– 2.059,979	DOAS Data Records in ASCII see table 36

Table 33: Extracted Level 2 Data Content

This yields an approximate size of ~2 MB (1.96 MB for the assumptions as made below) for one Level 2 Data product which covers a one orbit of data.

The GDP Software Identifier in ASCII (GSI2) structure for the Level 2 extraction software is given in the following table:

Field Number	Number of Bytes	Data Type	Byte Position	Description
1	80	A	1–80	Separator 1 (/*———————*\)
2	1 or 2	A	81	Line Separator, see comment in table 33
3	80	A	82–161	Software Version (** GDP Level 1 to 2 Extracting – Version 9.99 – Copyright DLR 1995 **)
4	1 or 2	A	162	Line Separator, see comment in table 33
5	80	A	163–242	Separator 2 (*———————*/)
6	1 or 2	A	243	Line Separator, see comment in table 33

Table 34: GDP Software Identifier

The Specific Product Header in ASCII (SPH2A) structure for the Level 2 Data product is given in the following table:

Field Number	Number of Bytes	Data Type	Byte Position	Description
1	38	PIR	1–38	Input Data References see table 3
2	1 or 2	char	39	Line Separator, see comment in table 33
3	6	A	40–45	GDP Software Version, DOAS Level 1 to 2, (XX . XX_)
4	5	A	46–50	GDP Software Data Bases Version, (XX . XX)
5	1 or 2	char	51	Line Separator, see comment in table 33
6	2	A	52–53	Number of Fitting Windows (Nwin=3) (99)
7	1 or 2	char	54	Line Separator, see comment in table 33
8	Nwin * 2 * 7 = 42	A	55–96	Window Pair (start and end wavelength in nm) (999.99_999.99_)
9	1 or 2	char	97	Line Separator, see comment in table 33
10	2	short	98–99	Number of Molecules (Nmol=7) (99)
11	1 or 2	char	100	Line Separator, see comment in table 33
12	Nmol * (1 + 12) = 91	A	101–191	Molecule Pair (fitting window number and molecule name) (9_XXXXXXXXXX_)
13	1 or 2	char	192	Line Separator, see comment in table 33

Table 35: Specific Product Header Content (Level 2)

The DOAS Data Record in ASCII (DDRA) structure is given in the following table:

Field Number	Number of Bytes	Data Type	Byte Position	Description
1	113	GLR2A	1–113	Geolocation Record in ASCII see table 37
2	12	A	114–125	Total Column of Ozone (Dobson) (–9.99999E–99)
3	1 or 2	char	126	Line Separator, see comment in table 33
4	12	A	127–138	Relative error on the Total Column (%) (–9.99999E–99)
5	1 or 2	char	139	Line Separator, see comment in table 33
6	1234	IRRA	140–1373	Intermediate Results Record in ASCII see table 38

Table 36: DOAS Data Record Content (Level 2)

The Geolocation Record in ASCII (GLR2A) structure is given in the following table:

Field Number	Number of Bytes	Data Type	Byte Position	Description
1	24	A	1–24	UTC Date & Time (DD.MMM.YYYY_HH:MM:SS.mmm)
2	1 or 2	char	25	Line Separator, see comment in table 33
3	8	A	26–33	Solar Zenith Angle of the Ground Pixel Centre (9999.99_)
4	8	A	34–41	Line–of–Sight Zenith Angle of the Ground Pixel Centre (9999.99_)
5	1 or 2	char	42	Line Separator, see comment in table 33
6	5 * 14 = 70	A	43–112	4 Corner and Center Coordinates of Ground Pixel (Latitude and Longitude) 5*(–99.99_999.99_)
8	1 or 2	char	113	Line Separator, see comment in table 33

Table 37: Geolocation Record 2 Content

The Intermediate Results Record in ASCII (IRRA) structure is given in the following table:

Field Number	Number of Bytes	Data Type	Byte Position	Description
1	Nmol * 13 = 91	A	1–91	*VCD*: Total VCD to ground of e.g. O_3^{UV}, O_3^{VIS}, NO_2^{UV}, NO_2^{VIS}, BrO, H_2O, SO_2 (–9.99999E–99_)
2	1 or 2	char	92	Line Separator, see comment in table 33
3	Nmol * 13 = 91	A	93–183	*VCD*: Errors on VCDs above (–9.99999E–99_)
4	1 or 2	char	184	Line Separator, see comment in table 33
5	5	A	185–189	*VCD*: Flag indexing output (99999)
6	1 or 2	char	190	Line Separator, see comment in table 33
7	Nmol * 13 = 91	A	191–281	*DOAS*: Slant Columns of e.g. O_3^{UV}, O_3^{VIS}, NO_2^{UV}, NO_2^{VIS}, H_2O, BrO, SO_2 (–9.99999E–99_)
8	1 or 2	char	282	Line Separator, see comment in table 33
9	Nmol * 13 = 91	A	283–373	*DOAS*: Errors on Slant Columns above (–9.99999E–99_)
10	1 or 2	char	374	Line Separator, see comment in table 33
11	Nwin * (4*13 + 1) = 159	A	375–533	*DOAS*: RMS, χ^2, Goodness of Fit, Iteration Number for the Nwin fitting windows 4*(–9.99999E–99_) Line Separator, see comment in table 33
12	5	A	534–538	*DOAS*: Flag indexing output (99999)
13	1 or 2	char	539	Line Separator, see comment in table 33
14	Nmol * 13 = 91	A	540–630	*AMF*: AMF to ground for species as listed above (–9.99999E–99_)
15	1 or 2	char	631	Line Separator, see comment in table 33
16	Nmol * 13 = 91	A	632–722	*AMF*: AMF to cloud–top for species as listed above (–9.99999E–99_)
17	1 or 2	char	723	Line Separator, see comment in table 33
18	Nwin * 13 = 39	A	724–762	*AMF*: Total intensities for ground for Nwin fitting windows † (–9.99999E–99_)
19	1 or 2	char	763	Line Separator, see comment in table 33
20	Nwin * 13 = 39	A	764–802	*AMF*: Total intensities for cloud–top for Nwin fitting windows † (–9.99999E–99_)
21	1 or 2	char	803	Line Separator, see comment in table 33
22	Nwin * 13 = 39	A	804–842	*AMF*: Measured Intensity for Nwin windows † (–9.99999E–99_)
23	1 or 2	char	843	Line Separator, see comment in table 33

24	5	A	844–848	*AMF*: Flag indexing output (99999)
25	1 or 2	char	849	Line Separator, see comment in table 33
26	2 * 13 = 26	A	850–875	*ICFA*: Cloud fraction and Cloud–top Pressure 2*(–9.99999E–99_)
27	1 or 2	char	876	Line Separator, see comment in table 33
28	2 * 13 = 26	A	877–902	*ICFA*: Errors on Cloud fraction and Cloud–top Pressure 2*(–9.99999E–99_)
29	1 or 2	char	903	Line Separator, see comment in table 33
30	13	A	904–916	*ICFA*: Surface Pressure (–9.99999E–99_)
31	1 or 2	char	917	Line Separator, see comment in table 33
32	5	A	918–922	*ICFA*: Flag indexing output (99999)
33	1 or 2	char	923	Line Separator, see comment in table 33
34	3 * 2 * 13 = 78	A	924–1001	*Statistics*: Pixel contrast (3 PMDs: mean and standard deviation) ‡ 3*2*(–9.99999E–99_)
35	1 or 2	char	1002	Line Separator, see comment in table 33
36	4 * (4 * 13 + 1 or 2) = 212	A	1003–1214	*Statistics*: Pixel colour (sub–pixel values) ‡ 4*(4*(–9.99999E–99_) + Line Separator, see comment in table 33)
37	13	A	1215–1227	*Statistics*: Pixel colour gradient (Ch. 3) ‡ (–9.99999E–99_)
38	1 or 2	char	1228	Line Separator, see comment in table 33
39	5	A	1229–1233	*Statistics*: Flag indexing output (99999)
40	1 or 2	char	1234	Line Separator, see comment in table 33

Table 38: Intermediate Results Record Content

* Note: Vertical Columns and Slant Columns are given in mol/cm^2
† Intensities returned as representative wavelenghts for the given windows (1 or 2 per window). Absolute Radiance Units.
‡ For definitions, see section 4.6 on page 15.
For definitions on flag indexing, see appendix A.2.

B Basic Data Representations

This appendix describes how GDP represents data in storage, specifically in the data products. This chapter is intended as a guide to programmers who wish to write their own reading modules in other languages or on other machines having a different representation of numbers.

Storage Allocation

The following table shows the storage allocation of the basic numeric data types which are used for GDP products:

Data Type	Internal Representation
`char`	a single 8–bit byte aligned on a byte boundary.
`short`	half word (two bytes or 16 bits), aligned on a two–byte boundary.
`long`	32 bits (four bytes or one word), aligned on a four–byte boundary.
`float`	32 bits (four bytes or one word), aligned on a four–byte boundary. A float has a sign bit, 8–bit exponent, and 23–bit fraction.
`double`	64 bits (eight bytes or two words), aligned on a double–word boundary. A double element has a sign bit, an 11–bit exponent and a 52–bit fraction.

Table 39: Data Type Storage Allocation

Data Representations

Bit numberings of any given data element used for GDP are as follows:

- Bit 0 is the least significant bit of one byte;
- Byte 0 is the most significant byte of a given data element.

The most significant bit of the `char`, `short` and `long` data types is a sign bit. The `unsigned` versions of these data types use all bits for representation of the number, but do not known negative values.

`float` and `double` data elements are represented according to the "ANSI IEEE" 754–1985 standard.

Bits	Content
8–15	Byte 0
0–7	Byte 1

Table 40: Short Data Type Representation

Bits	Content
24–31	Byte 0
16–23	Byte 1
8–15	Byte 2
0–7	Byte 3

Table 41: Long Data Type Representation

Bits	Name	Content
31	Sign	1 if number is negative.
23–30	Exponent	Eight–bit exponent, biased by 127. Values of all zeros, and all ones, reserved.
0–22	Fraction	23–bit fraction component of normalised significand. The "one" bit is "hidden".

Table 42: Float Data Type Representation

Bits	Name	Content
63	Sign	1 if number is negative.
52–62	Exponent	Eleven–bit exponent, biased by 1023. Values of all zeros, and all ones, reserved.
0–51	Fraction	52–bit fraction component of normalised significand. The "one" bit is "hidden".

Table 43: Double Data Type Representation

A `float` and `double` number is represented by the form:

$$(-1)^{Sign} \cdot 2^{(exponent - bias)} \cdot 1.fraction$$

where "1.*fraction*" is the significand and "*fraction*" are the bits in the significand fraction.

Appendix C

Interface Specification Document

of the

GOME Data Processor

Please refer to Appendix B, the "Product Specification Document of the GOME Data Processor."

The document which previously formed Appendix C, the "Interface Specification Document of the GOME Data Processor" (ER-IS-DLR-GO-0004 Iss./Rev. 1/B, 16 December 1994), and the former document in Appendix B, the "Product Specification Document of the GOME Data Processor" (ER-AD-DLR-GO-0016 Iss./Rev. 1/A, 30 September 1994), were superseded at press time by the new document now in Appendix B, the "Product Specification Document of the GOME Data Processor" (ER-PS-DLR-GO-0004 Iss./Rev. 2/A, 11 September 1995). This was done to provide the most complete and up-to-date information possible. Due to lack of time, the text of this document could not be modified to reflect this change. The Editor apologises for any inconvenience this may have caused.

Appendix D

Coverage Plots

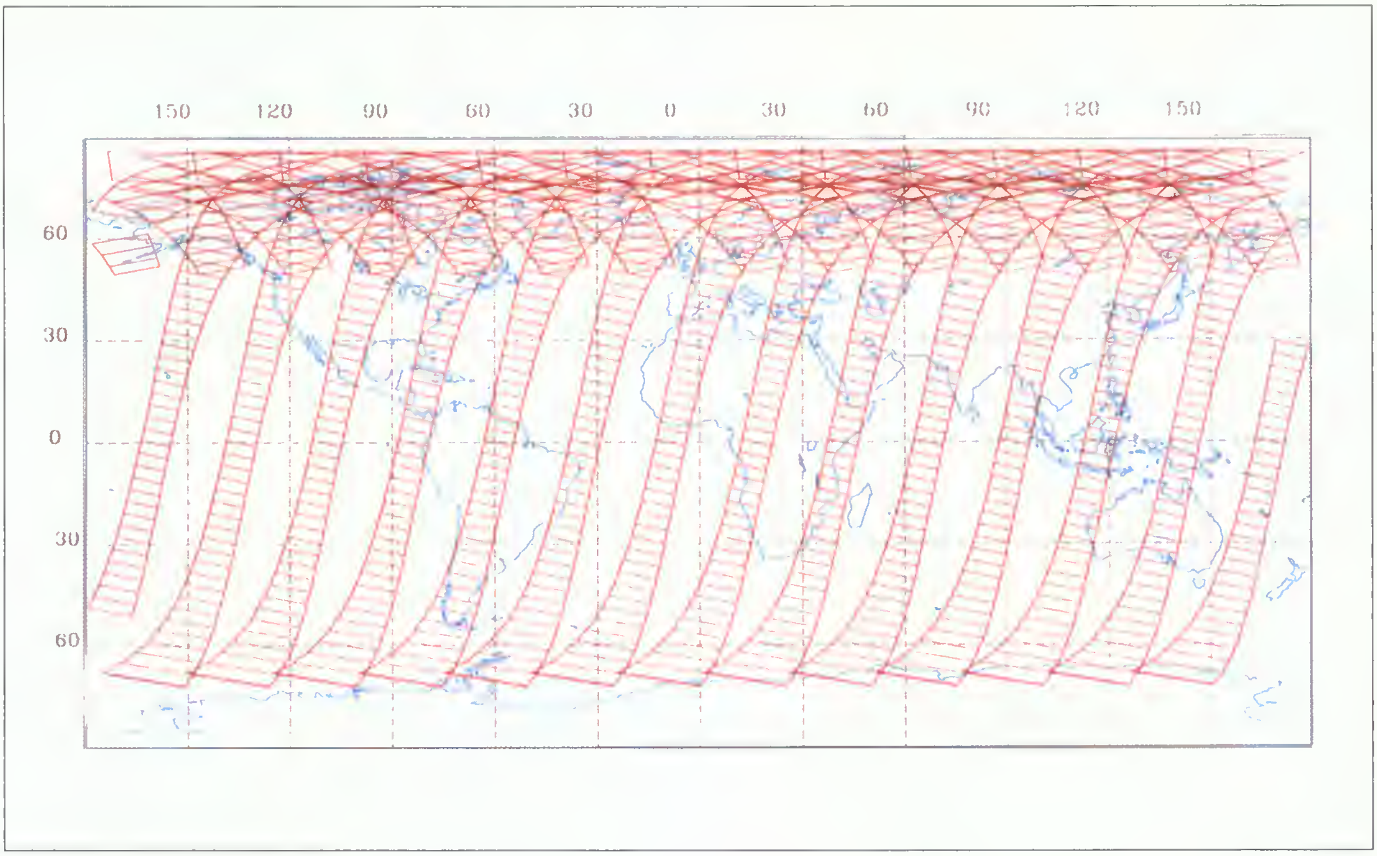
On the following pages, a number of plots indicate the various coverage features of the GOME instrument.

Plots are either in x-y projection or as polar projections. All have been made for the 35-day repeat cycle of ERS-2. The effect of illumination conditions is considered; therefore, the plots are referenced for a particular day, i.e., summer solstice. The horizontal bars in the coverage plots correspond to the ground pixel size for the longest integration time (channel 1).

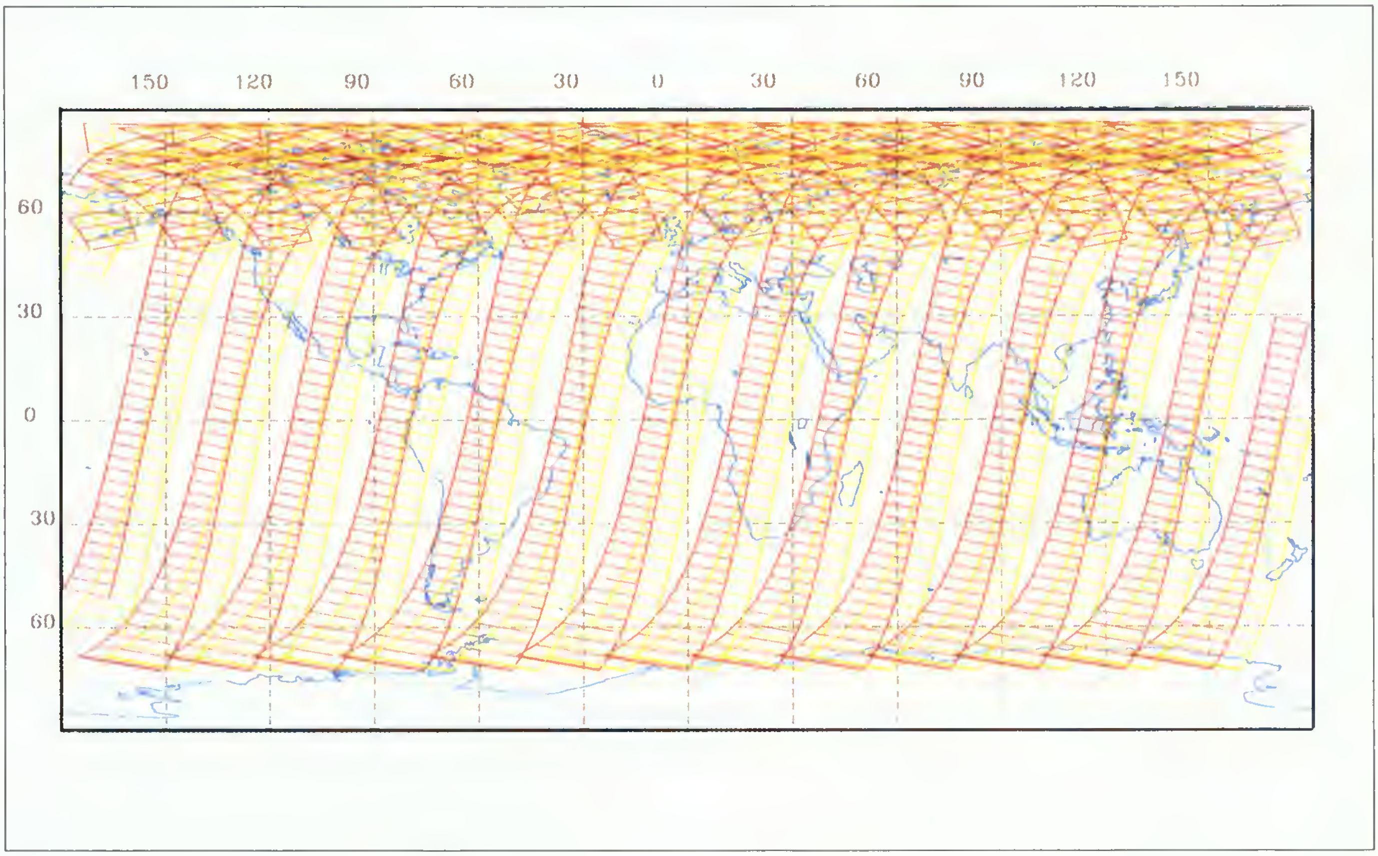
Plots 1 to 3 show the coverage of GOME for 1, 2, and 3 days, respectively. Although the repeat cycle of the satellite is 35 days, the largest GOME swath of 960 km enables nearly global coverage to be achieved within 3 days; that is, "nearly" global coverage because a gap is left about the poles. One gap is caused by the effect of the orbit inclination and the sensor field-of-view; the other gap is caused by the illumination conditions. Plots 4 and 5 demonstrate this for the summer solstice in the North and South polar projections, with the coverage achieved within one day.

Plots 6 to 9 show the effect on the one-day coverage of the various swath widths which can be commanded. They can be compared with Plot 1, which shows the largest swath used by default. Plot 10 shows the traces as achieved within three days if no scanning is done at all. (This is the pattern of subsatellite point tracks for this period).

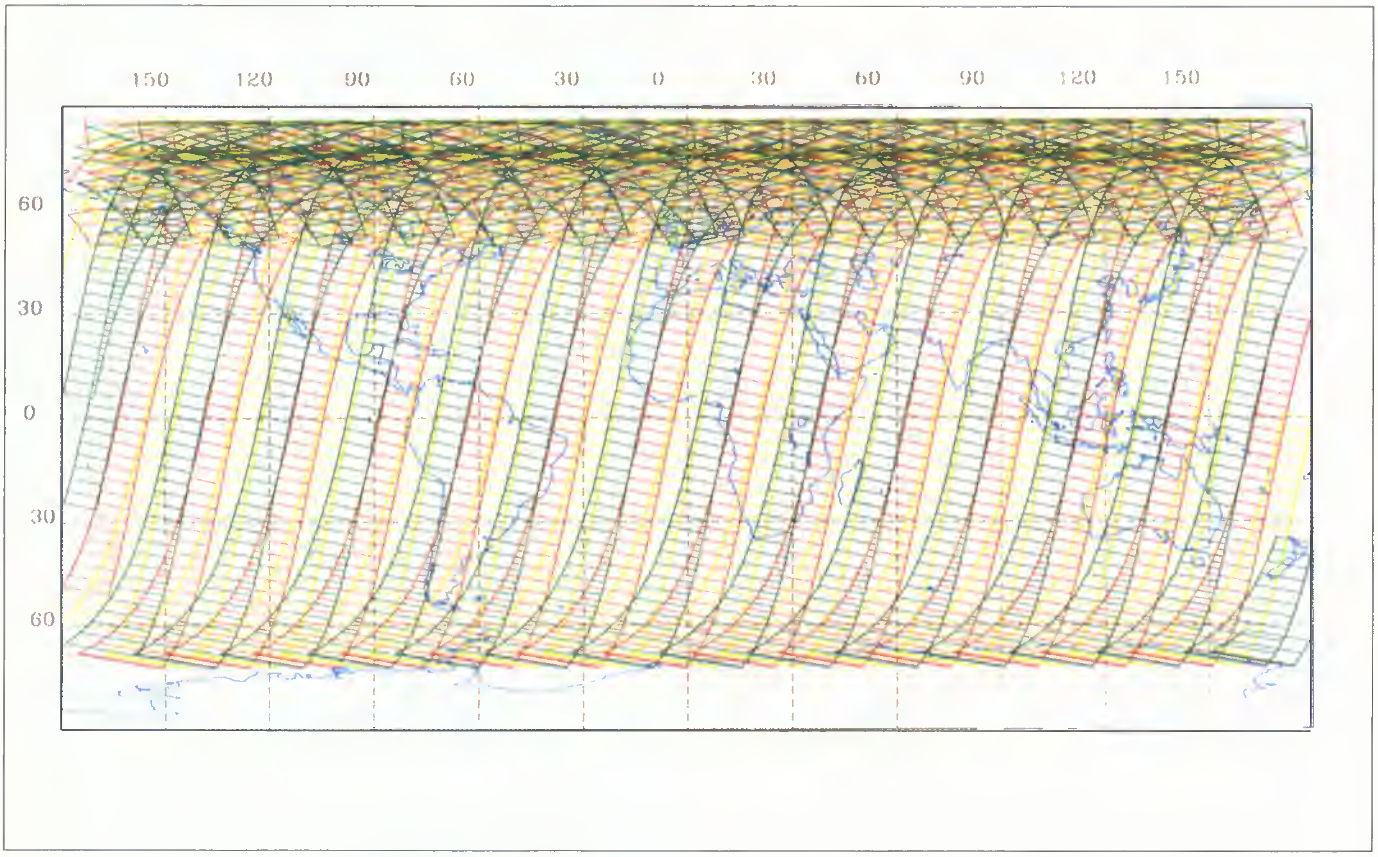
Plots 11 and 12 show again the North and South polar projections, respectively, of the normal 960 km swath, now with the varying pixel size as a result of the illumination indicated (as per timelines in Appendix A). Plots 13 and 14 show the effect of using the polar timeline (in the illustrated case, the North Polar Observation Timeline, NPOT): in Plot 13, it is used continuously (for every orbit), whereas in Plot 14, it is interleaved with NOT. One can see that in both cases the hole in the coverage completely disappears. For clarity, one single orbit with polar view is repeated in Plot 15.



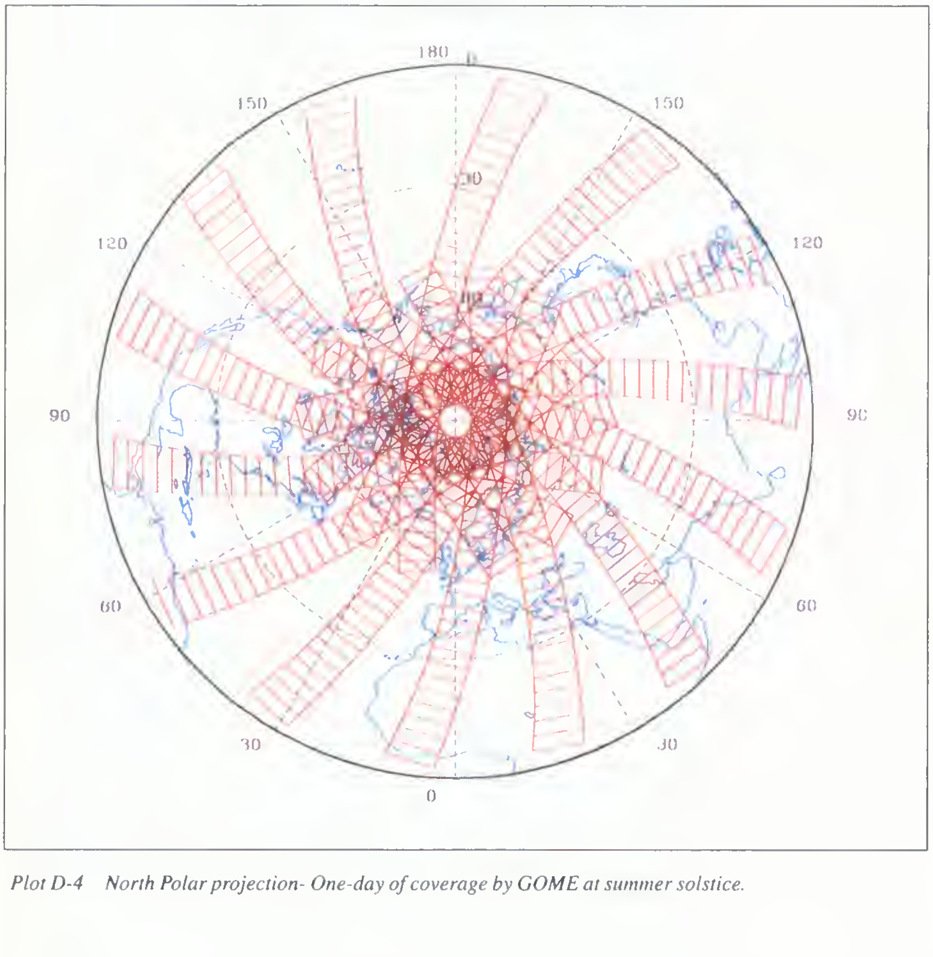
Plot D-1 One-day of coverage by GOME using 960 km swath.



Plot D-2 Two-days of coverage by GOME using 960 km swath.

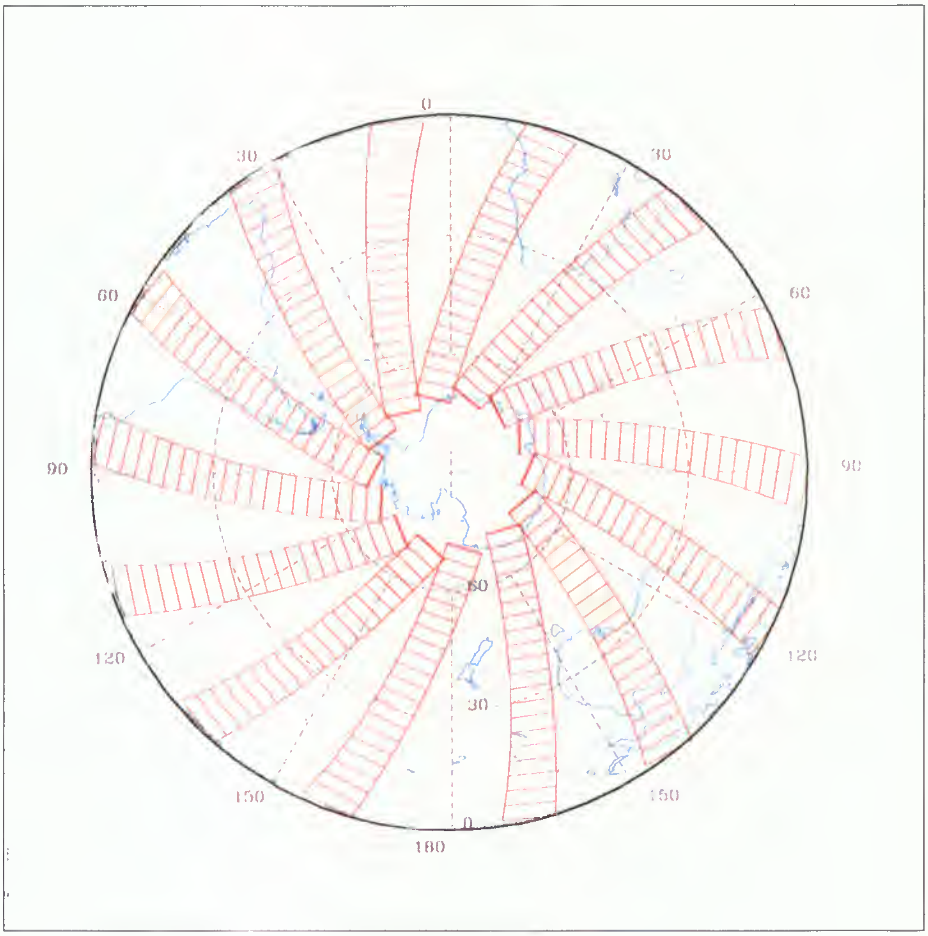


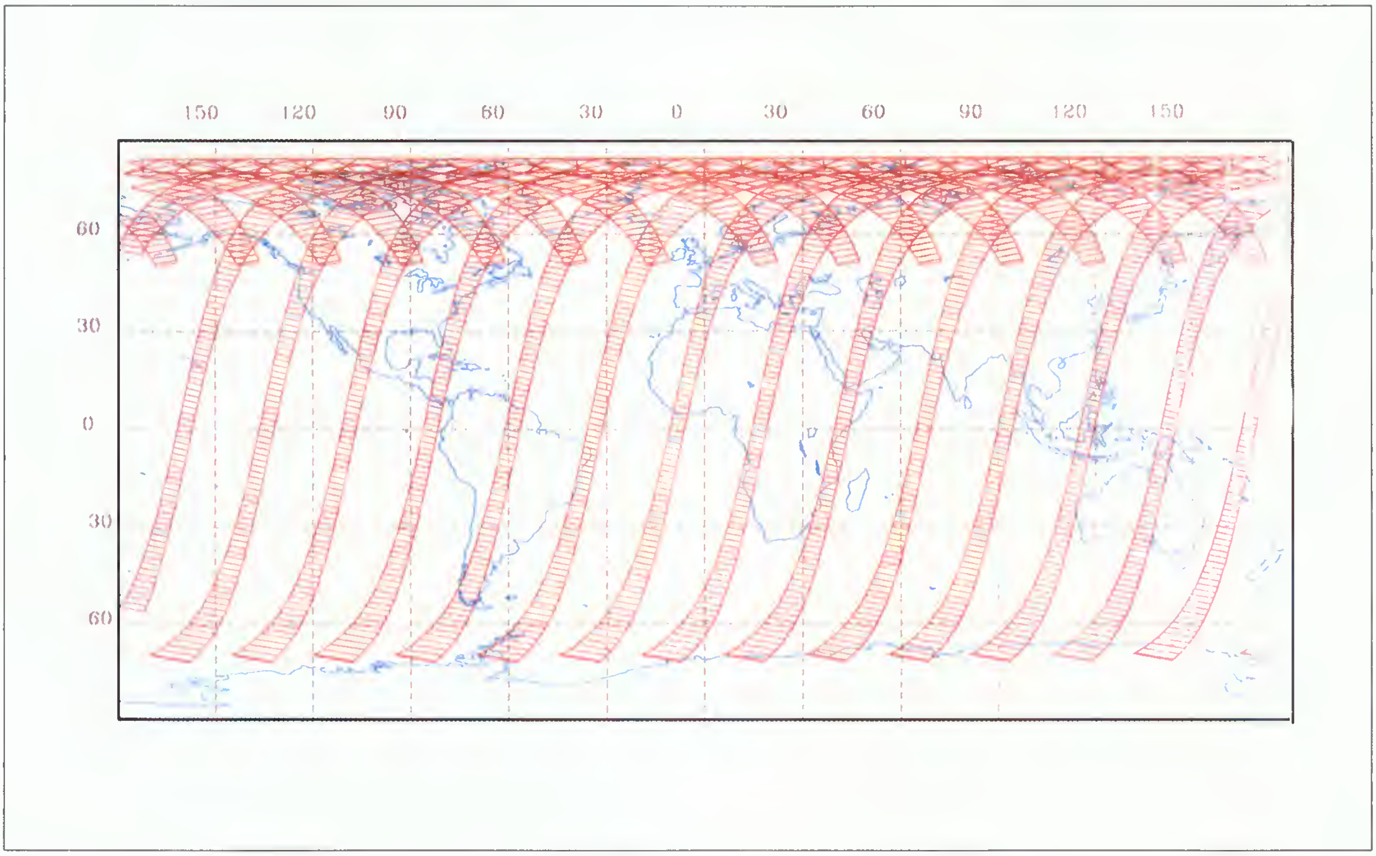
Plot D-3 Three-days of coverage by GOME using 960 km swath- near global coverage.



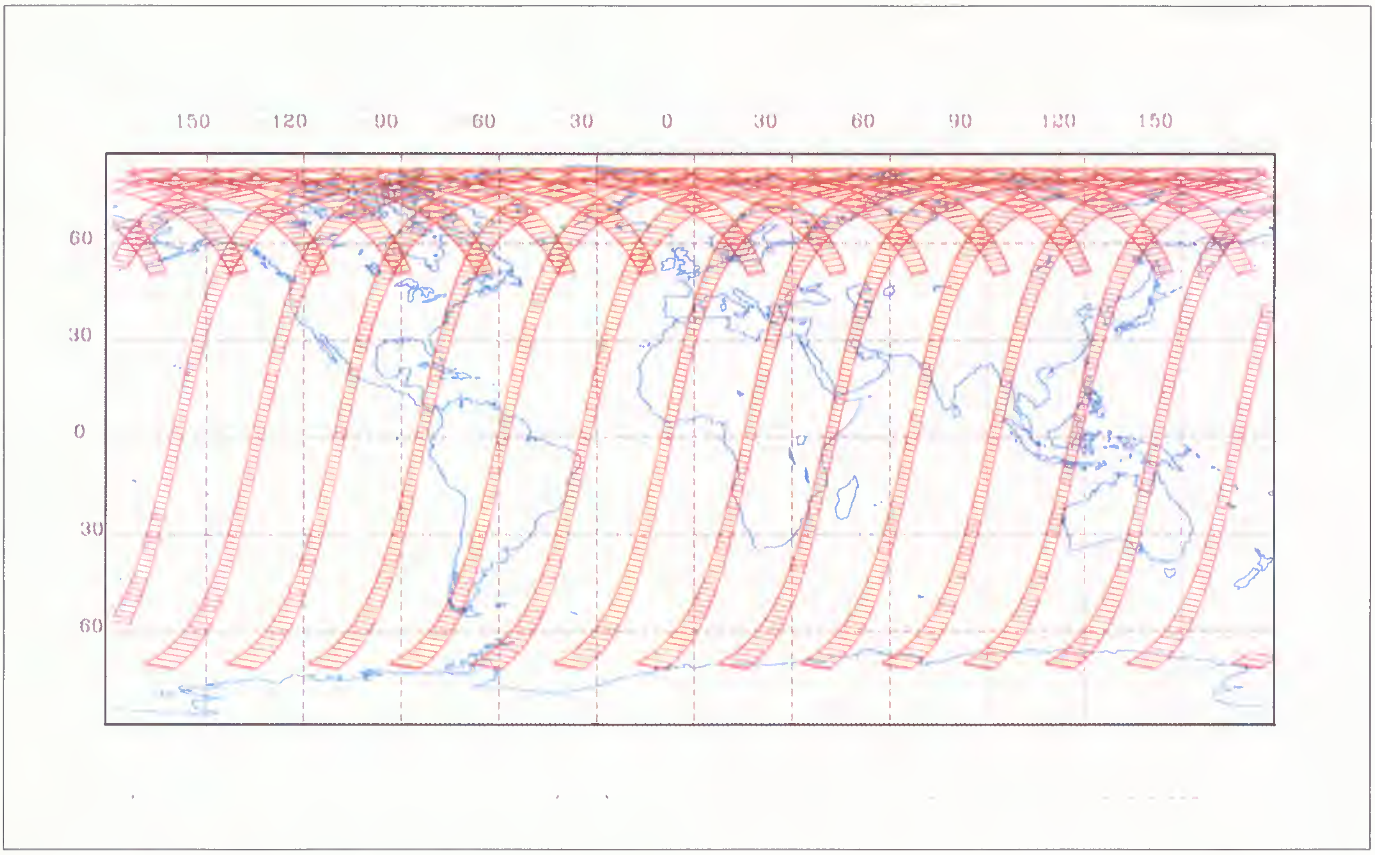
Plot D-4 North Polar projection- One-day of coverage by GOME at summer solstice.

Plot D-5 South Polar projection- One-day of coverage by GOME at summer soltice.

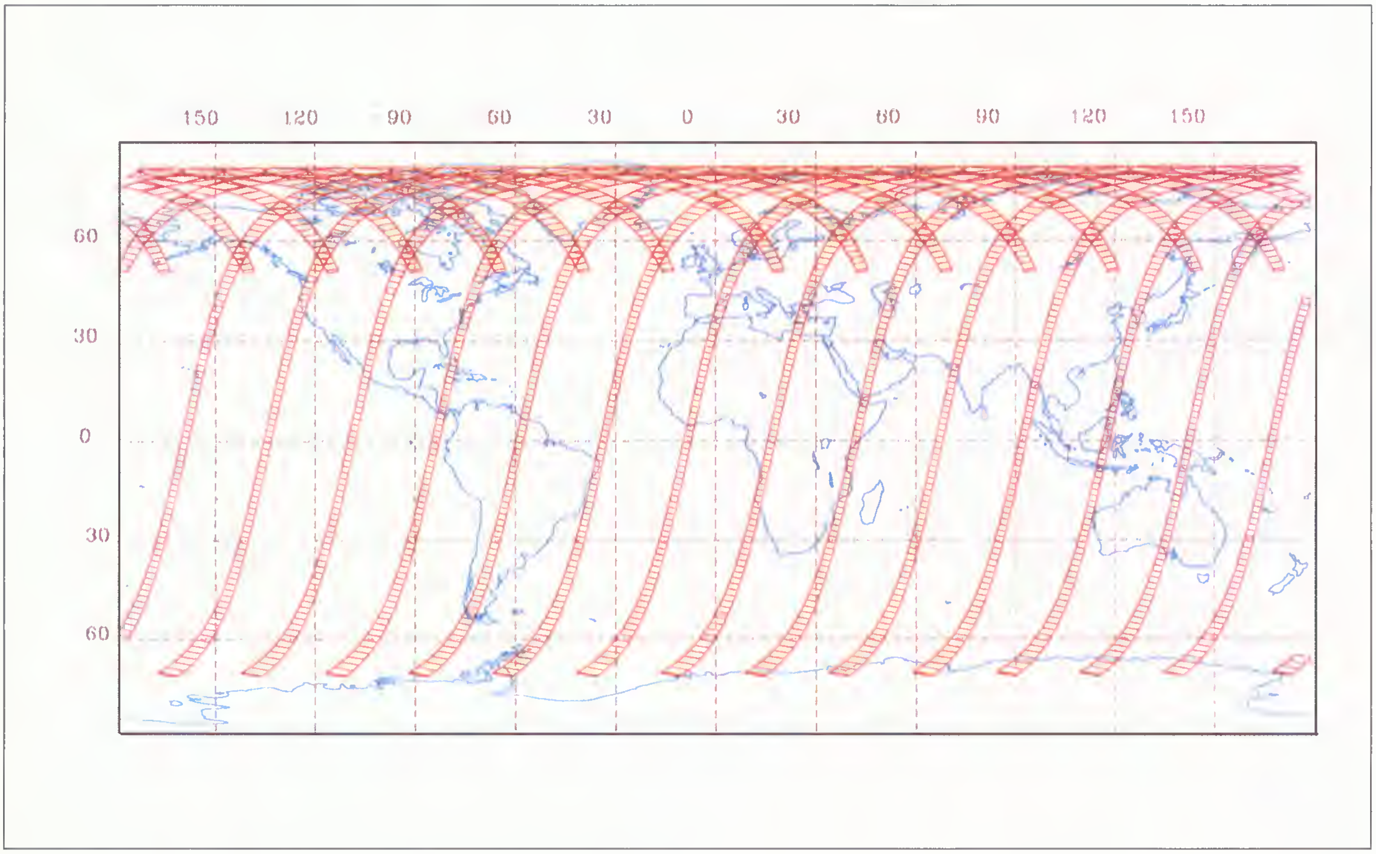




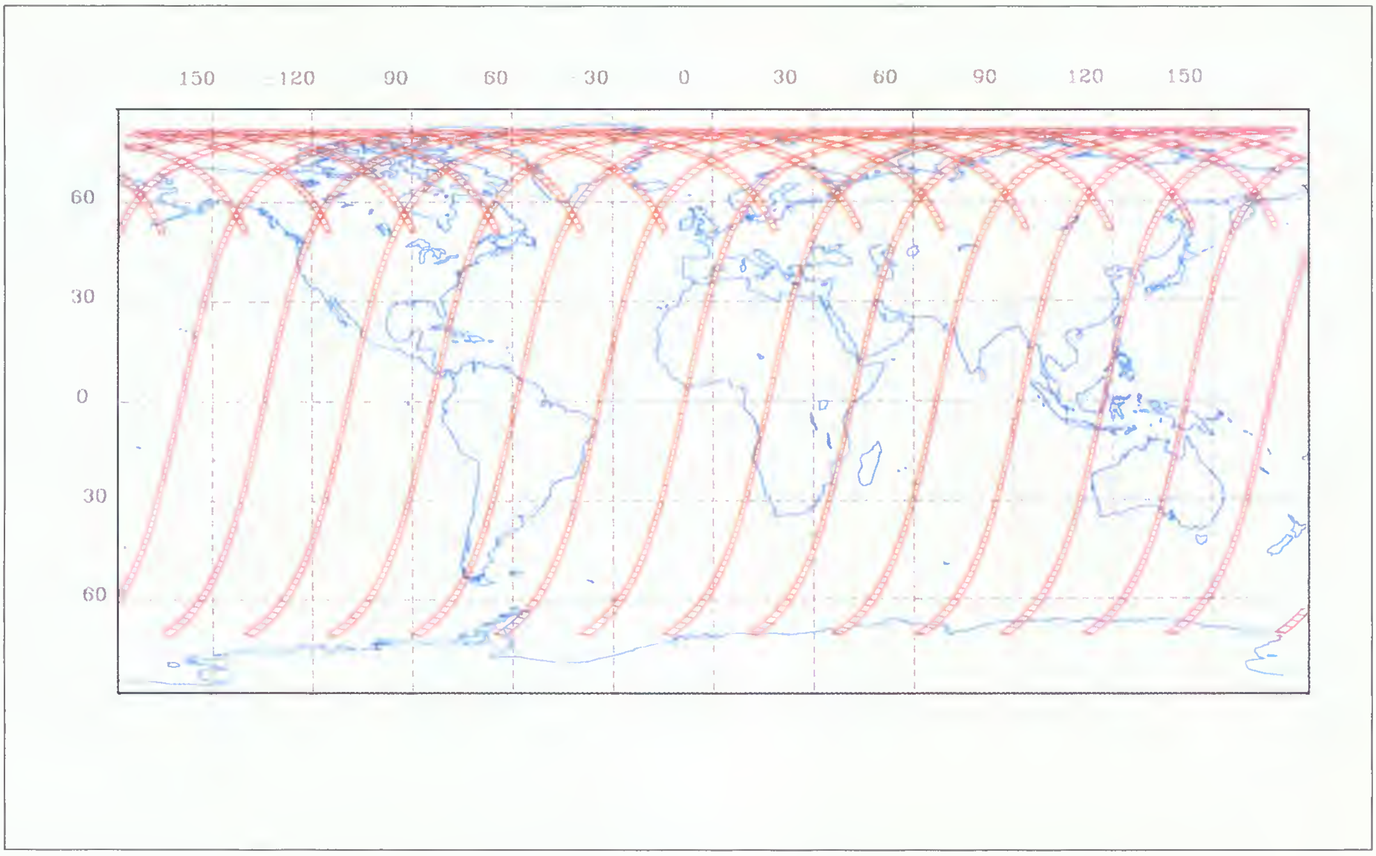
Plot D-6 One day of coverage by GOME using reduced swath width of 480 km.



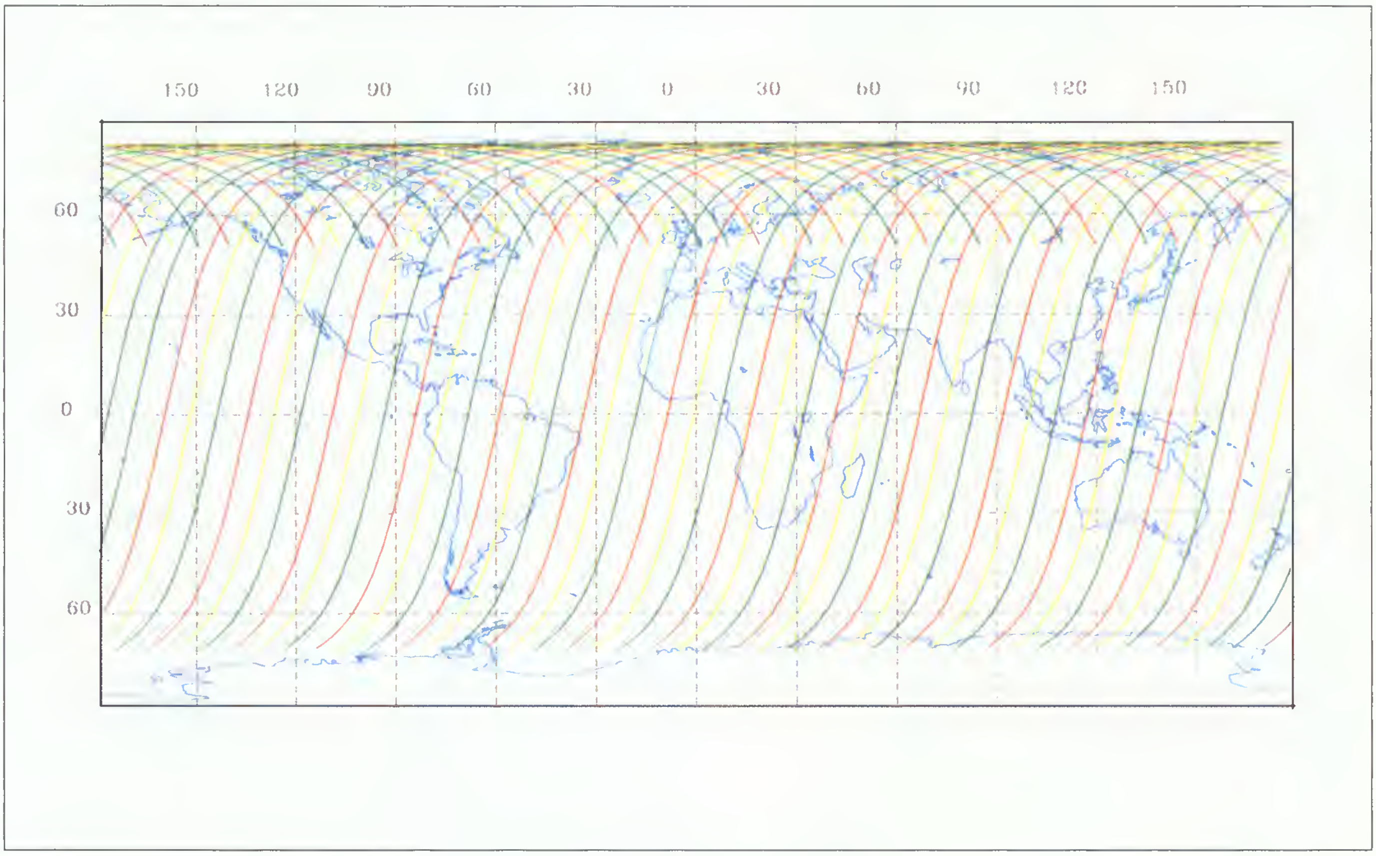
Plot D-7 One-day of coverage by GOME using reduced swath width of 360 km.



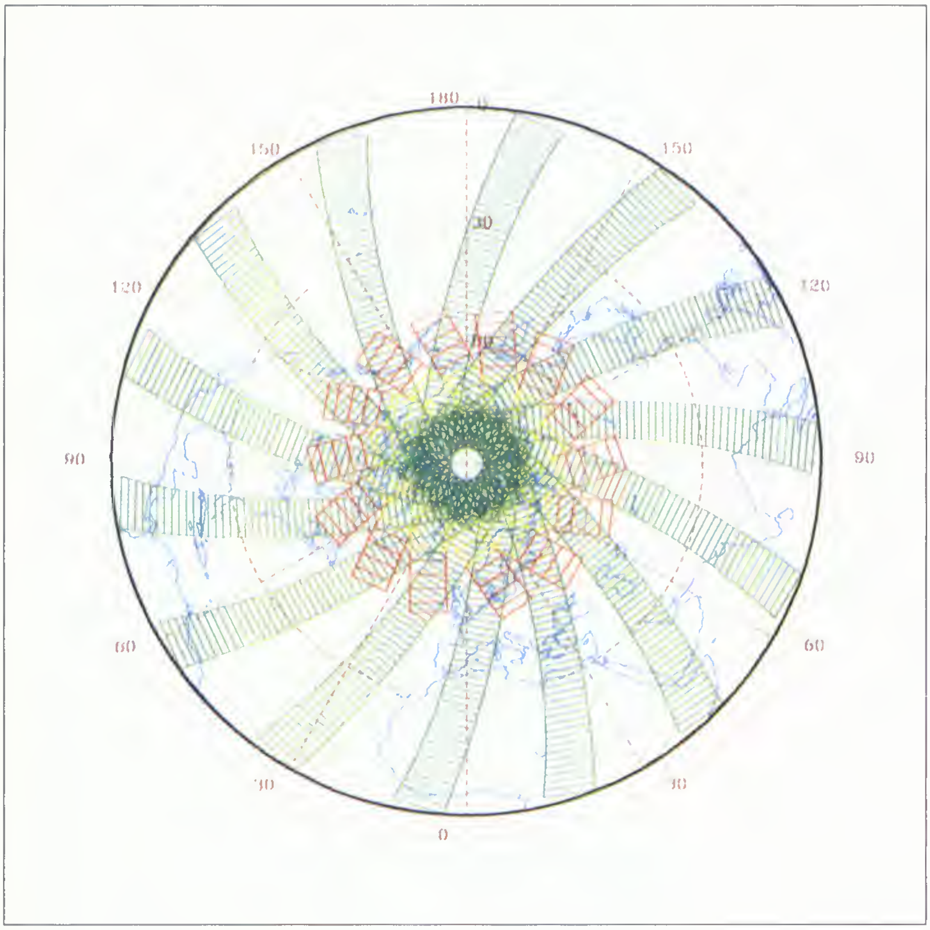
Plot D-8 One-day of coverage by GOME using reduced swath width of 240 km.



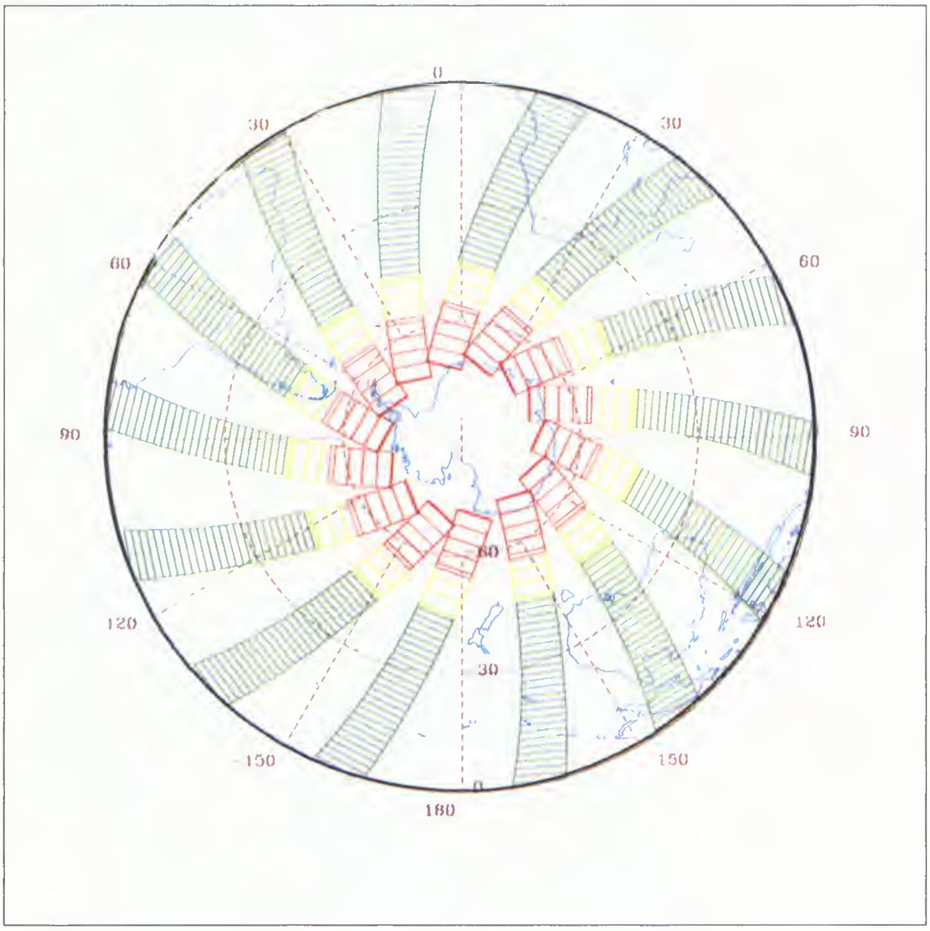
Plot D-9 One-day coverage by GOME using reduced swath width of 120 km.



Plot D-10 Track over the Earth of the ERS-2 satellite over a three-day period (static Nadir pointing).

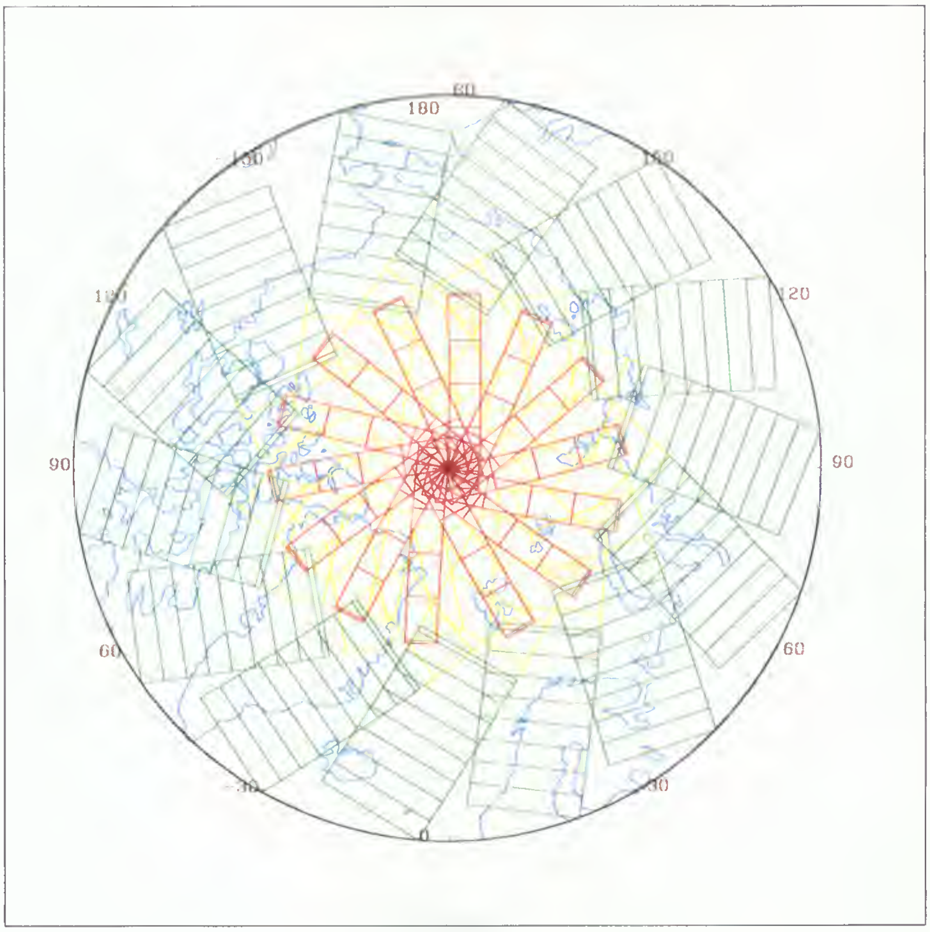


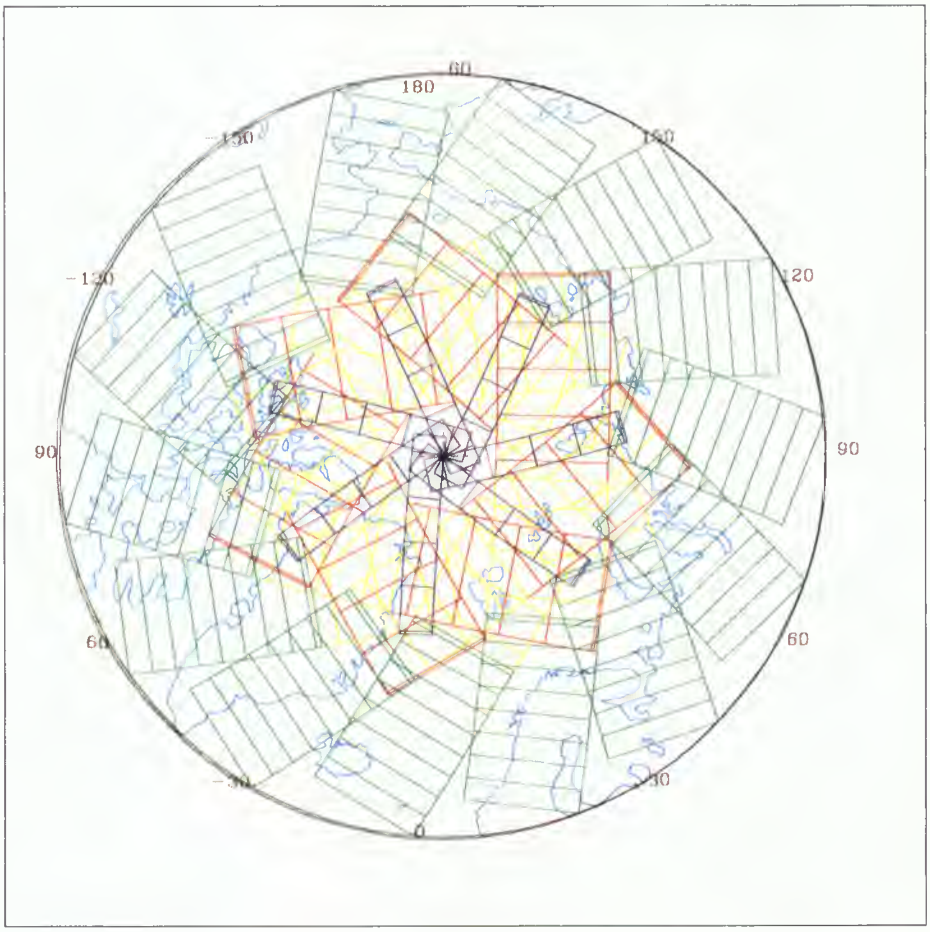
Plot D-11 North Polar projection of 960-km swath coverage by GOMJE.



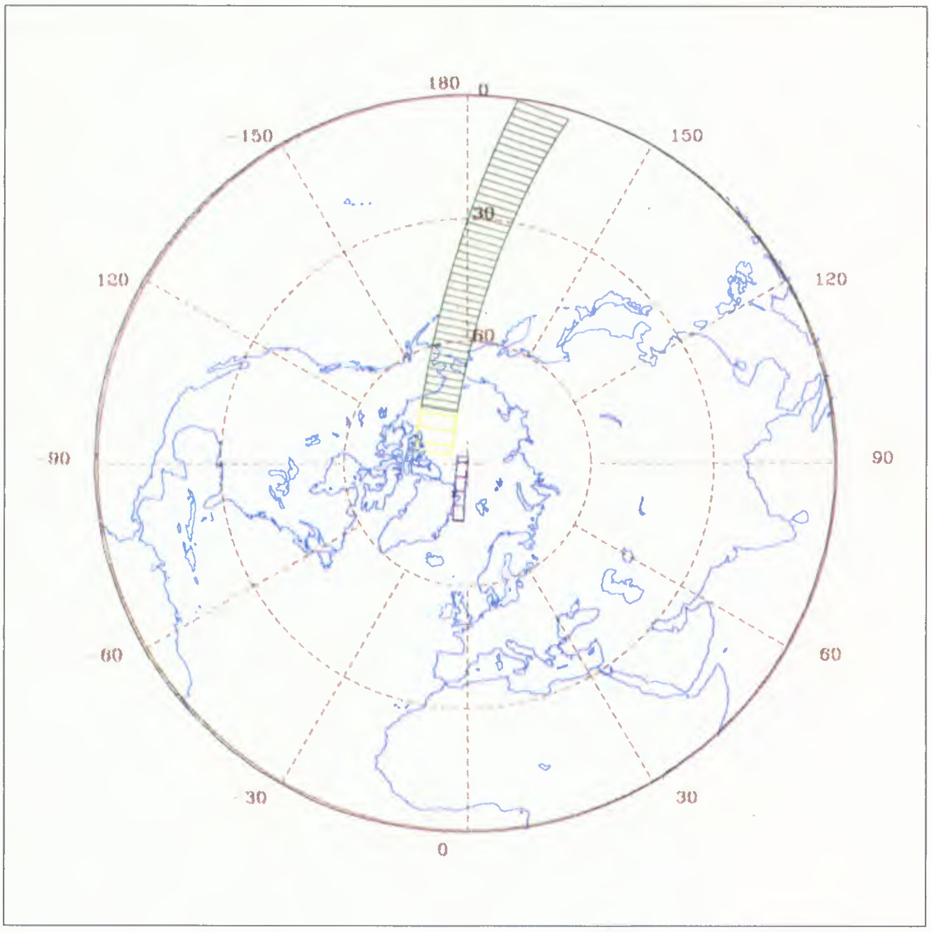
Plot D-12 South Polar projection of 960-km swath coverage by GOME.

Plot D-13 GOME coverage using the North Polar Observation Timeline (NPOT) continuously.





Plot D-14 GOME coverage using the North Polar Observation Timeline (NPOT) interleaved with the Normal Observation Timeline.



Plot D-15 Polar view of coverage from a single orbital pass by ERS-2/GOME.

Appendix E

Product Order Form

This Product Order Form should be addressed to:

ERS Order Desk
ESRIN
CP 64
I-00044 Frascati
Italy

Phone:(+39) 6-941 80 336 or 406 or 457
Fax:(+39) 6-941 80 510
Telex:610637 ESRIN I

Inquiries may also be addressed to:

ESRIN ERS Help Desk
ESRIN
via Galileo Galilei
I-00044 Frascati
Italy

Phone:(+39) 6-941 80 600
Fax:(+39) 6-941 80 510
Telex:610637 ESRIN I

Note: As of press time, the detailed conditions for obtaining GOME data products were not yet defined. Certain restrictions or fees might be imposed, depending upon decisions by the ESA programme board.

NAME

DATE

PROJECT

DETAILS OF THE REQUEST

SENSOR	**PRODUCT/S**	**MEDIUM/S**
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AREA NAME ....

AREA COORDINATES (in degrees and minutes)

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lat .... **long** ....

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TIME PERIOD

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