

# International Conference on Space Optics—ICSO 1997

Toulouse, France

2–4 December 1997

*Edited by George Otrio*



## *The ENVISAT Michelson interferometer for passive atmospheric sounding: MIPAS*

*Martin Endemann, Philippe Garé, Herbert Nett, Jörg Langen, et al.*



icso proceedings



International Conference on Space Optics — ICSO 1997, edited by Georges Otrio, Proc. of SPIE Vol. 10570, 105700G · © 1997 ESA and CNES · CCC code: 0277-786X/18/\$18 · doi: 10.1117/12.2326450

## The ENVISAT Michelson Interferometer for Passive Atmospheric Sounding: **MIPAS**

**Martin Endemann, Philippe Garé, Herbert Nett, Jörg Langen**  
ESA-ESTEC, P.O.Box 299, NL-2200AG Noordwijk, The Netherlands

**David J. Smith, Karl Hoerning**  
Dornier Satellitensysteme GmbH, P.O.Box 80 11 69, D-81663 Munich, Germany

**Roland Gessner**  
Dornier Satellitensysteme GmbH, P.O.Box 1031, D-88039 Friederichshafen, Germany

### **ABSTRACT**

*The Michelson Interferometer for Passive Atmospheric Sounding (MIPAS) is a high resolution Fourier-transform spectrometer which is being developed as one of the ESA payload instruments to be flown on-board the ENVISAT environmental satellite. MIPAS will be used to measure concentration profiles of atmospheric constituents, as well as profiles of temperature and pressure on a global scale over a period of several years.*

*This paper gives an overview of the current development status of the instrument and present the expected performance based on the Engineering Model tests.*

### **1 MIPAS's ROLE**

Since the eighties, changes in global ozone concentration in the Earth's atmosphere have been observed and the concern on an enhanced greenhouse effect caused by anthropogenic emissions is increasing. To advance the understanding of these alarming effects further, global data about the mixing ratios of the relevant, photochemically interrelated species in the upper troposphere and the middle atmosphere are required.

MIPAS is a space borne Fourier-Transform Spectrometer (FTS) conceived for global observations of these atmospheric trace species. It observes wide spectral intervals throughout the mid infra-red with high spectral resolution in limb geometry. After suitable ground processing, these spectra allow to quantify concentration and mixing ratio profiles of numerous atmospheric trace species. These species include the complete NO<sub>x</sub>-family and several CFC's. In addition, atmospheric temperature as well as pressure will be derived. Distribution of aerosol and cloud layers (including Polar Stratospheric Clouds) may also be determined from MIPAS data.

MIPAS is capable to determine these atmospheric parameters:

- all simultaneously with each measurement,
- with complete global coverage,
- during day- and night time conditions (allowing to observe the diurnal variation of trace species), and
- throughout its mission duration of four years.

Thus MIPAS provides unique capabilities and promises to become an important research tool for atmospheric sciences. For this reason, it has been selected as an ESA payload for the large European environmental satellite ENVISAT-1), which is planned for launch on an Ariane-5 by the end of this decade. ENVISAT is so far the most ambitious European earth observation spacecraft, and with a mass of 8.8 tons and a length of 10 m, it is a rather large satellite

## 2 MIPAS's CAPABILITIES

### 2.1 Measurement Requirements

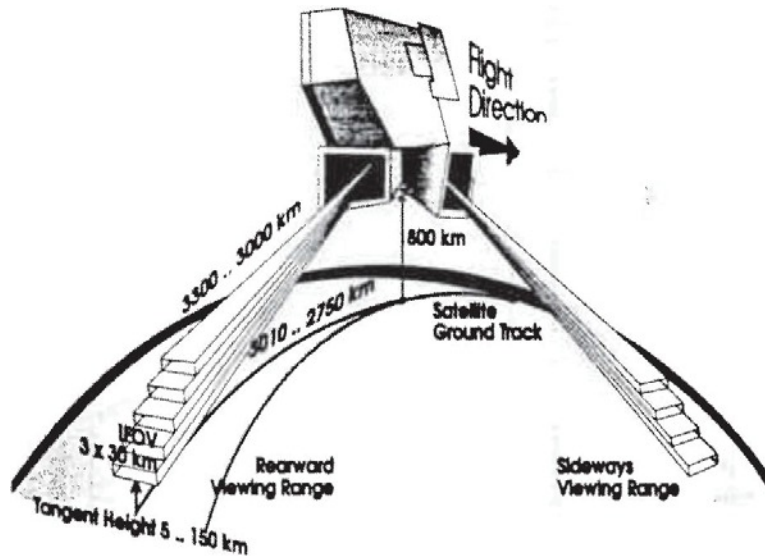


Figure 1 Viewing geometry of MIPAS

range, and sideways (in the anti-sun direction) within a  $30^\circ$  wide arc. For all routine measurements the IFOV will be in the rearward viewing range, as it provides a good earth coverage including the polar regions. The sideways range is important for observation of 'special events', like volcano eruptions, trace gas concentrations above major air traffic routes, or concentration gradients along the dusk/dawn lines.

As a result of the limb viewing geometry, the distance between instrument and tangent point is about 3300 km. Thus, in order to measure at a predetermined limb height, the pointing of instrument and satellite in elevation direction must be excellent. It is possible to determine the geometric limb height by pointing information from the spacecraft with a standard deviation below 900 m, corresponding to a Line-of-Sight elevation pointing accuracy of better than 0.28 mrad ( $1\sigma$ )

To provide useful measurements, MIPAS has to meet ambitious performance requirements. Tab. 1 summarizes the key pointing, spectral and radiometric requirements.

Fig.1 indicates the basic observation geometry of MIPAS. The instantaneous field-of-view (IFOV) is only 3 km high to achieve a good vertical resolution, but 30 km wide to collect sufficient radiance, which corresponds to an angular range at the instrument of 0.9 mrad (vertical) by 9 mrad (horizontally).

MIPAS is capable to steer the IFOV within two pointing regimes: rearwards (in the anti-flight direction) within a  $35^\circ$  wide

Tab 1: Summary of MIPAS performance requirements

<b>Pointing Requirements</b>	
Instantaneous Field-of-View	3 x 30 km <sup>2</sup> (height x width)
elevation pointing	5 ... 210 km above earth limb
azimuth pointing	35° rearwards, 30° sideways
pointing stability ( $1\sigma$ )	0.08 mrad over 4 s 0.14 mrad over 75 s
pointing knowledge	0.28 mrad
<b>Spectral Requirements</b>	
spectral range	685 .. 2410 cm <sup>-1</sup> (14.6 .. 4.15 μm)
spectral resolution	0.035 cm <sup>-1</sup> (unapodized)
spectral resolution modes	total 50000 spectral samples per spectrum at full spectral resolution; reduced to 1/10 full spectral resolution for special measurements
<b>Radiometric Requirements</b>	
radiometric sensitivity NESR	50 ... 4.2 nW/cm <sup>2</sup> /sr/cm <sup>-1</sup>
absolute radiometric accuracy	1 % (@ 14.6 μm) ... 3 % (@ 4.15 μm) of input radiance
<b>Operations Requirements</b>	
max. time per spectrum	4.6 s (full spectral resolution) 1.0 s (1/10 spectral resolution)
time per elevation scan	75 s (500 km ground trace)
spectra per elevation scan	16 (full spectral resolution) 75 (1/10 spectral resolution)

will be required. A very high stability of all assemblies affecting the pointing is a design driver for MIPAS as well as for the ENVISAT satellite. To compensate bias angles (e.g. from launch shifts) and harmonic pointing variations during the orbit, the Line-of-Sight will be recalibrated during flight by viewing stars, as discussed in section 3.6.

Pointing stability during one interferometer sweep (4 s duration) will be much higher - predictions indicate a worst case height variance below 300 m (0.1 mrad).

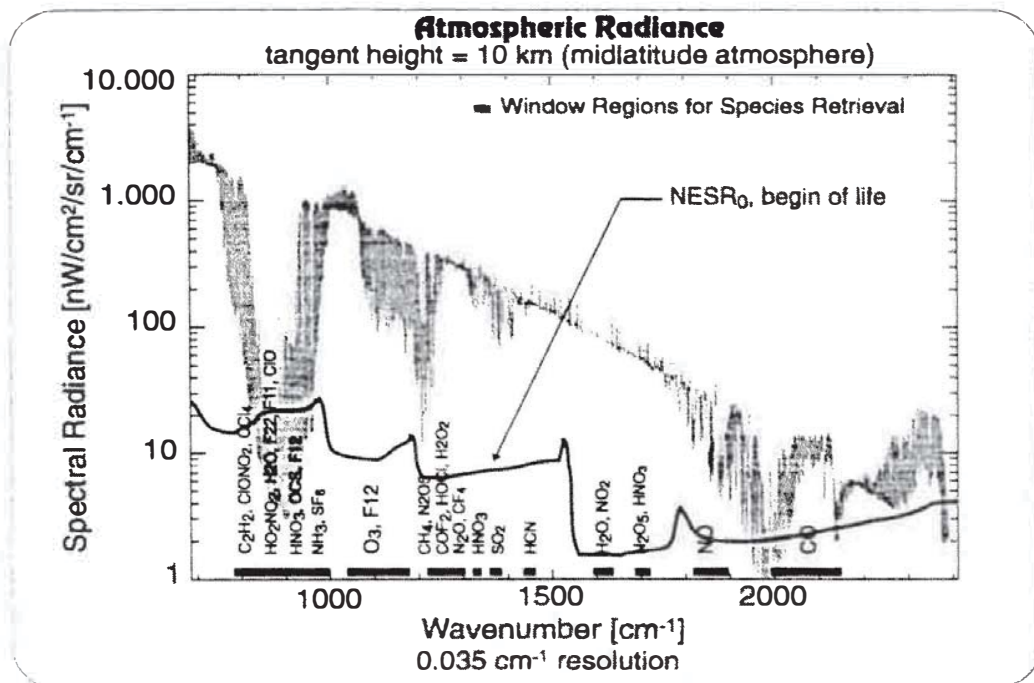
The spectral coverage ranges from  $685 \text{ cm}^{-1}$  ( $14.6 \mu\text{m}$ ) to  $2410 \text{ cm}^{-1}$  ( $4.15 \mu\text{m}$ ). This range covers most of the mid infrared region, and contains numerous strong, characteristic emission lines of most atmospheric species. A Fourier-Transform spectrometer is ideally suited to perform measurements of such wide spectral coverage with highest possible sensitivity.

Fig. 2 shows the atmospheric radiance as expected at a tangent altitude of 10 km. The large amount of atmospheric emission lines in this spectral region is evident. The bottom of that figure indicates the regions where the species of high interest show strong emission lines. Concentration profiles of these species can be determined by analysing the effective strength of specific lines from spectra with different tangent altitudes.

The high spectral resolution (unapodized) of better than  $0.035 \text{ cm}^{-1}$  (corresponding to 1 GHz resolution or  $0.006 \text{ nm}$  at a wavelength of  $4.15 \mu\text{m}$ ) is necessary to reduce the interference of overlapping spectral features. With this high spectral resolution, MIPAS provides a total of about 50,000 independent spectral samples in each spectrum.

A complete high resolution spectrum is obtained every 4.5 s. MIPAS can also perform measurements with a lower spectral resolution in shorter time.

The radiometric requirements on MIPAS are highly demanding. A good radiometric sensitivity is a major



**Figure 2** Atmospheric radiance as predicted for 10 km tangent altitude over the full spectral range of MIPAS, and the Noise Equivalent Spectral Radiance NESR predicted for the flight model. Spectral regions with emission lines of specific species are indicated on the bottom.

design driver to allow detection of weak atmospheric signals without additional averaging. Radiometric sensitivity is expressed here by the Noise Equivalent Spectral Radiance (NESR), which characterizes the instrument noise in terms of incident radiance. The required sensitivity must be better than  $50 \text{ nW/cm}^2 \text{ sr cm}^{-1}$  at the long wavelength side, decreasing to  $4.2 \text{ nW/cm}^2 \text{ sr cm}^{-1}$  at the short wavelength side. The actual instrument performance (as predicted for the flight model) is also indicated in Fig. 2. It meets the requirements in all bands.

A good absolute knowledge of the received radiance is important to retrieve the atmospheric temperature of the emitting layer, which is a key parameter in the data retrieval. This need for data with an excellent radiometric accuracy is quite challenging: a calibration accuracy in the 1 - 3 % range is difficult to achieve even for ground based instruments. But the test results of MIPAS indicate that this demanding requirement will be met as well.

## 2.2 MIPAS Operation

MIPAS performs continuously measurements, which are either atmospheric observations (i.e. useful atmospheric spectra are derived), or are used for instrument calibrations (subdivided into radiometric calibration and pointing calibration).

### Atmospheric Measurements

To retrieve concentration profiles, MIPAS obtains a series of spectra with different tangent altitudes, typically starting at about 70 km altitude, and then descending in 5 or 3 km steps down to 7 km. As a spectrum is obtained in about 4.5 s, such an elevation scan sequence of 18 spectra takes 80 s. During this time, the spacecraft covers a ground-track distance of about 530 km, but due to the downward scanning the measurement distance increases during the scan, so that the actual spread of tangent points is only 400 km.

For most measurements, MIPAS will view the atmosphere through the rear baffle, and will autonomously move the azimuth mirror within the  $35^\circ$  wide range to cover both, the arctic and the antarctic polar regions.

The actual elevation scan sequence can be freely updated in flight to allow an easy adaptation to the user needs. In addition, time tagged 'special events' can be commanded with free azimuth and elevation angle ranges, which allow observations for more specific research interest, like pollution monitoring along air traffic routes, observation of concentration changes along the dawn/dusk line, concentration profiling near volcanic eruptions or support of regional measurement campaigns.

### Radiometric Calibration

Radiometric calibration of MIPAS is performed with two measurements:

**offset calibration**, by observation of cold space to determine the internal emission of MIPAS (which will be the major source for offset in the spectra),

**gain calibration**, by observation of the well characterized internal calibration black body source to calibrate the instrument response throughout the spectral bands. Gain calibration also provides the information about phase distortions used for the phase correction of the interferograms during ground processing.

Offset calibration has to be performed relatively frequently (several times per orbit) to determine all variations of the instrument self emission due to temperature variations. It takes about 20 s. It comprises several low resolution interferometer sweeps that are co-added by the ground segment to reduce noise.

Gain calibration is planned to be performed much less frequently (once per day or less). It comprises a number (about 1000) of black body and cold space measurements performed at low spectral resolution, which are co-added on ground to reduce the random noise. The temperature of the calibration black

body is also down linked to provide the basis for the conversion into an absolute radiance units.

The phase correction of interferograms is very critical for the correct radiometric calibration. After long trade-offs between various different phase correction schemes it was decided early on that for an emission sensing interferometer like MIPAS the best correction is performed together with the radiometric calibration: the (complex) offset spectrum must be subtracted from both, the scene spectrum and the calibration black body spectrum. These offset-corrected spectra then are divided by each other for the proper gain- and phase correction. However, this scheme only works if the phase shifts of the interferograms remain constant throughout the time between two black body measurements. This requirement of an excellent long-term phase stability is one of the design drivers for the MIPAS instrument.

### Pointing Calibration

Another set of calibration measurements is performed in-flight to determine the actual Line-of-Sight (LOS) pointing biases and harmonic variations, which in turn set the tangent altitude of a particular measurement. This LOS-calibration is based on the observation of stars moving through the IFOV with the short wavelength channels. The actual time of star observation is correlated with the expected time as computed by the pointing information from the Attitude & Orbit Control System (AOCS) of ENVISAT. Thus all biases and slow pointing variations between the star tracker package of ENVISAT (providing the pointing reference for the AOCS) and the LOS of MIPAS are derived and used for pointing corrections. The LOS-calibration will be repeated rather infrequently, like once per month.

### 2.3 Ground Processing

On-board data processing is reduced to the minimum required to reduce the data rate (i.e. analog and digital filtering of the detector outputs, decimations of the data streams and word length reduction of transmitted data blocks).

During the Level-1 processing in the ENVISAT ground segment, the interferograms to the different channels are converted to a fully (radiometrically and spectrally) calibrated spectrum, which is also corrected for the Doppler-shift from the moving platform.

The available pointing data are converted into the tangent height (including the correction for atmospheric refraction), and the geographic coordinates of the tangent point.

Level-2 processing at the ENVISAT ground segment uses these Level-1 spectra from a complete elevation scan sequence to derive the profiles of temperature and pressure in a first step, and the concentration and mixing ratio profiles of selected species of highest priority: ozone  $O_3$ , water vapor  $H_2O$ , methane  $CH_4$ , nitrous oxide  $N_2O$ , and nitric acid  $HNO_3$ .

Other species contained in the spectra will be retrieved by other data centers or by research groups using similar algorithms as those in the ENVISAT ground segment.

## 3 DESIGN FEATURES

### 3.1 Architecture

The functional block diagram of MIPAS and its ground segment is outlined in Fig. 3. The atmospheric radiance enters MIPAS through the **Front End Optics (FEO)**, which comprises the Azimuth and Elevation Scan Units for the selection of the line-of-sight, the anamorphic telescope and the calibration blackbody for in-flight radiometric calibration.

From the telescope, the radiance is directed to the **Interferometer (INT)**, which could be considered the 'heart' of the instrument. The velocity of the two moving retro-reflectors is controlled to close

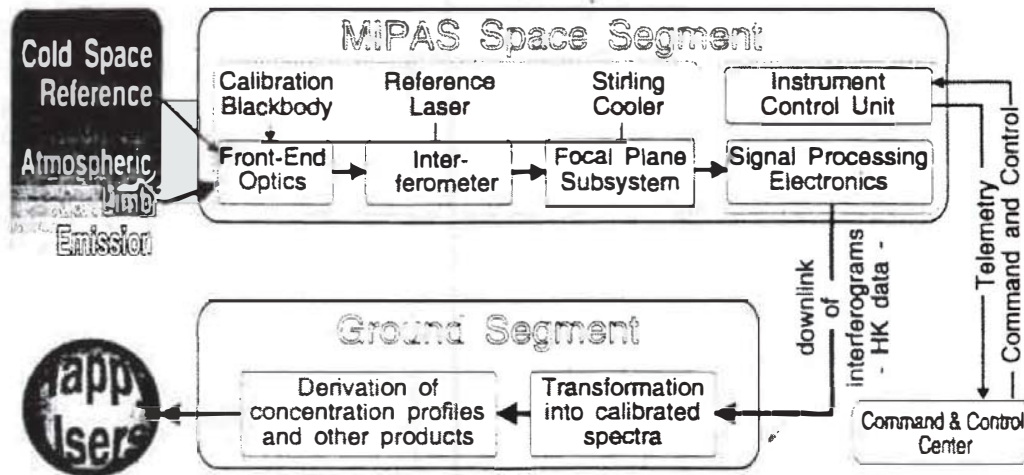


Figure 3 Functional block diagram of MIPAS, including the ENVISAT ground segment

tolerances using a laser interferometer.

The interferograms are detected by the **Focal Plane Subsystem (FPS)**, which divide the incoming light into various spectral channels for detection by the eight Hg:Cd:Te-detectors. The detectors are cooled by a pair of synchronized Stirling-cycle coolers to 70 K for maximum sensitivity. The detector output is filtered and decimated in the **Signal Processing Electronics (SPE)**, which outputs the interferograms and the ancillary data required for the on-ground processing to the Platform Data Handling & Transmission interface of the PPF for downlinking to the ground station.

In the **Ground Segment**, the downlinked interferograms are converted into calibrated atmospheric spectra. In the next processing levels, these spectra are used to retrieve the concentration profiles of the relevant atmospheric species and other, higher data products.

An **Instrument Control Electronics (ICE)** contains all electronics modules to supervise and to execute macro-commands for MIPAS, and it also houses the plug-in modules to drive the FEO and INT subsystems. The Stirling coolers of the FPS are controlled by a dedicated electronics box.

### 3.2 Accomodation on ENVISAT

Fig. 4 shows the overall layout of MIPAS as mounted on the tip of ENVISAT-1. It comprises the following modules:

- the MIPAS Optics module (MIO) with the azimuth and elevation scan units and the receiving telescope, the interferometer and the focal plane subsystem, mounted on the tip of ENVISAT.

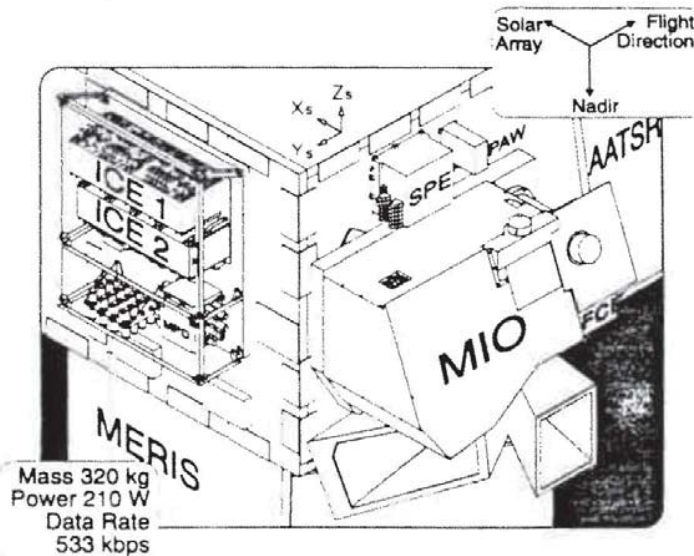


Figure 4 MIPAS on ENVISAT-1, with the optics module (MIO) on the tip, and electronics on side and around MIO. Not shown is the ICE radiator, and the instrument harness

- the MIPAS Electronics module (MIE) on the side of ENVISAT, with redundant Instrument Control Electronics boxes (ICE 1 & 2), the MIPAS Power Distribution unit (MPD) mounted on a common carrier plate and under a common radiator for thermal control, and
- Signal Processor Electronics (SPE), Detector Preamplifiers (PAW) and Stirling-cooler drive electronics (FCE) surrounding the Optics Module on the deep-space side of ENVISAT.

The optics module is about 1.36 m long (in flight direction), 1.46 m high (nadir direction) and about 0.74 m deep (cold space direction). It has a mass of about 170 kg. The total mass of the instrument will be about 320 kg, and its power consumption is budgeted to 210 W.

The housing of the Optics Module carries several radiators:

- a large radiator to cool all optical components of the instrument to about 205 K to reduce the thermal background of the instrument.
- two separate radiators to cool the compressor of the Stirling cycle coolers and to precool the Focal Plane Subsystem that keeps the detectors at about 70 K.

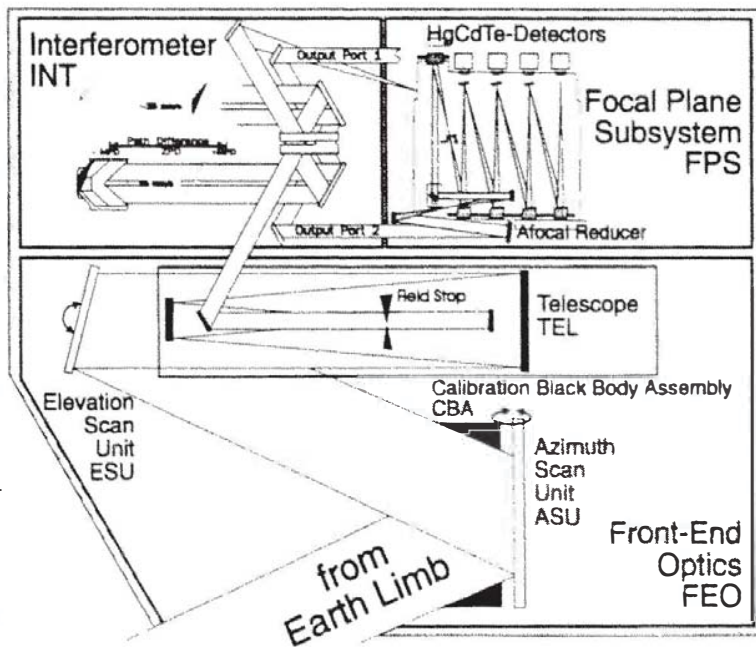
All radiators are tilted away from nadir by 20° to reduce the earth shine and thus to improve their efficiency. This tilt gives the Optics Module a distinctive wedge shape.

Below the Optics Module are the two baffles that reduce the amount of straylight entering MIPAS. The baffle for the rearward viewing range extends sufficiently far from the first optical component to avoid sunlight to enter, when the south pole region is observed during the summer period. In this case, the minimum angle between sun and line-of-sight could become as small as about 8 deg. It is cut short on the sun illuminated side to reduce its heat input. Further reduction of the baffle temperature is achieved by using a white coating (in the thermal IR it is black).

### 3.3 Optical Design Features

Fig. 5 shows the schematic layout of the optics module, indicating the optical path of MIPAS from the entrance baffle to the detector elements in the cold unit. The optical layout of the major assemblies is clearly visible in the drawing. Not shown are the Stirling-cycle coolers which are located above the Focal Plane Subsystem.

The entrance aperture of MIPAS accepts an input beam of 165 mm height and 55 mm width. This free aperture is reduced by two Lyot-stops (in the interferometer and before the detectors) to 135 mm by 45 mm for efficient stray



**Figure 5** Arrangement of the optical subsystem in the MIPAS optics module. The atmospheric radiance enters below through the baffle, is attached via the Azimuth and Elevation Scan Units and the anamorphic telescope the dual-slit interferometer. The two exits from the interferometer lead to two afocal reducers and the two sets of four HgCdTe detectors.



light rejection.

From the entrance aperture in the Azimuth Scan Unit (which comprises the largest optical component of MIPAS), the beam is reflected to the Elevation Scan Unit, which is designed for very high pointing stability as it determines the tangent height. Fig. 6 shows the flight model of the ESU during final testing.

From there the light enters the anamorphic telescope, which reduces the dimensions to 25 mm by 50 mm (in elevation and azimuth, respectively). The telescope also houses the field stop that determines the instrument field-of-view.

The position of the field stop in front of the instrument ensures that all detectors view the same air volume.

The interferometer can be considered as the heart of MIPAS. As seen in Fig. 5, it has a folded optical path to allow a more compact construction. Fig. 7 shows the actual MIPAS interferometer hardware during its integration. The dimensions of the interferometer are 0.58 m long and 0.36 m wide, and its mass is about 30 kg.

The interferometer optics comprises the beam splitter assembly, flat steering mirrors and the cube-corner retro-reflectors. Main design constraints result from the large temperature range (180 K to 300 K) over which performance must be maintained, which is particularly critical for the cube-corners.

The identical interferometer drive units perform the translation of the cube-corners. Linear motors generate the drive force. The cube-corners are guided by dry-lubricated roller bearings that run over stainless-steel rods. The lifetime requirement of four years continuous operation of MIPAS translate into a total of 40 million interferometer strokes, or 20 million motion cycles for this mechanism. The lifetime qualification has been successfully completed.

Sampling of the interferogram, as well as the difference velocity of the two slides are controlled via the built-in laser interferometer. It uses a single-mode 1.3  $\mu\text{m}$  diode-laser as a

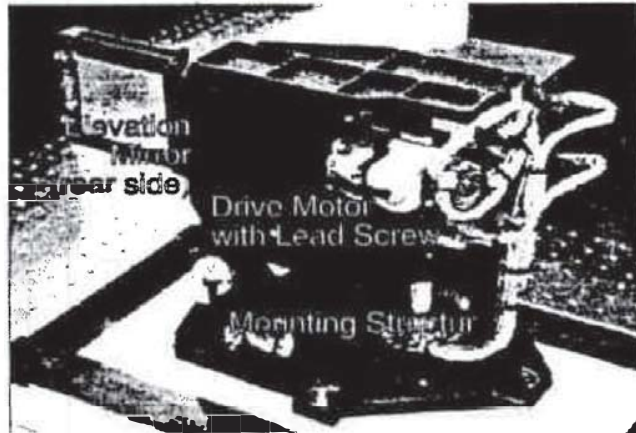


Figure 6 Elevation Scan Unit during final tests

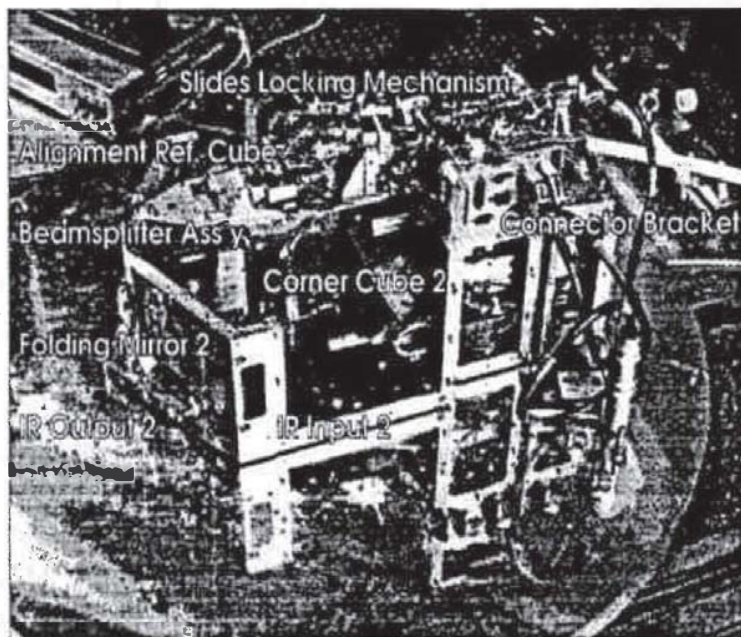
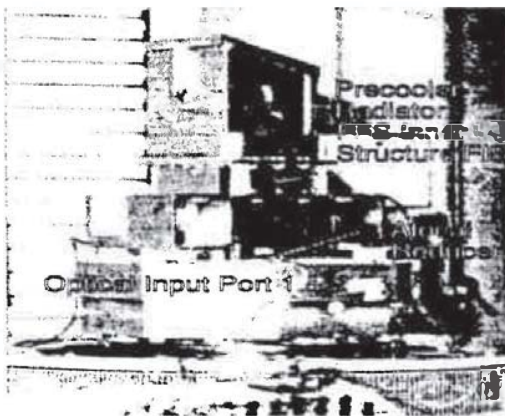


Figure 7 MIPAS interferometer during integration

source, which is temperature stabilized to limit the frequency drifts to well under 50 MHz over 200 s periods. However, no absolute frequency control is used as the spectra can easily be calibrated using known atmospheric emission lines.

The laser package is mounted remotely from the interferometer to minimize the heat load for the cooled optics. The laser radiation is guided via single-mode polarizing optical fiber into the interferometer. Although the individual components are proven in many communication systems, their use in a space borne instrument with operation over a wide temperature range is new and has required extensive testing for space qualification.

The two output beams from the interferometer are reduced in size by two off-axis Newton telescopes, and directed into the cold focal plane subsystem (see Fig. 8). This houses the signal detectors with their interfaces to the active coolers, as well as the associated optics required for spectral separation and beam shaping.



**Figure 8** Focal Plane Subsystem housing the detectors in a 70 K environment after vibration testing

For best radiometric sensitivity, a set of four Hg: Cd:Te detectors are used for each output port. In the long-wavelength region (6.5 to 14.6  $\mu\text{m}$ ), photoconductive detectors are used, while the two shorter-wavelength pairs are photo-voltaic types. All detectors are cooled to 70 K to reduce their internal noise contribution.

The preamplifiers are individually optimized for each detector to fulfil the stringent requirements on noise, phase distortions and linearity. The cold part of the preamplifiers is mounted in the detector housing, while final amplification is performed in an externally mounted package at room temperature.

#### 4 DEVELOPMENT STATUS

For the MIPAS development, the following model philosophy has been implemented:

- The Structure Model (StM), which has been used for the structural qualification on ENVISAT-1 level in 1996.
- The Reduced Engineering Model (REM), which is electrically and logically identical with the full MIPAS model and is used for the software validation and the testing of the integrated system on the ENVISAT-1 engineering model (EM). MIPAS-REM was delivered in Sep. 1996 for integration to the ENVISAT-1 EM.
- The MIPAS Engineering/Qualification Model (EQM), which is used for the qualification activities on instrument level. All subsystems for the EQM have been fully qualified, and the integrated instrument is undergoing its performance verification tests in a dedicated thermal vacuum chamber.
- The MIPAS Flight Model, which is presently integrated after all subsystems have been already tested to acceptance levels. Performance characterization tests in thermal vacuum will commence soon.

Figs. 9 and 10 show the theMIPAS optics module (EQM) during its final inspection before the sidewalls and the radiator on top are mounted. The picture shows the location of the key optical subsystems and gives a feeling for the size and complexity of MIPAS.

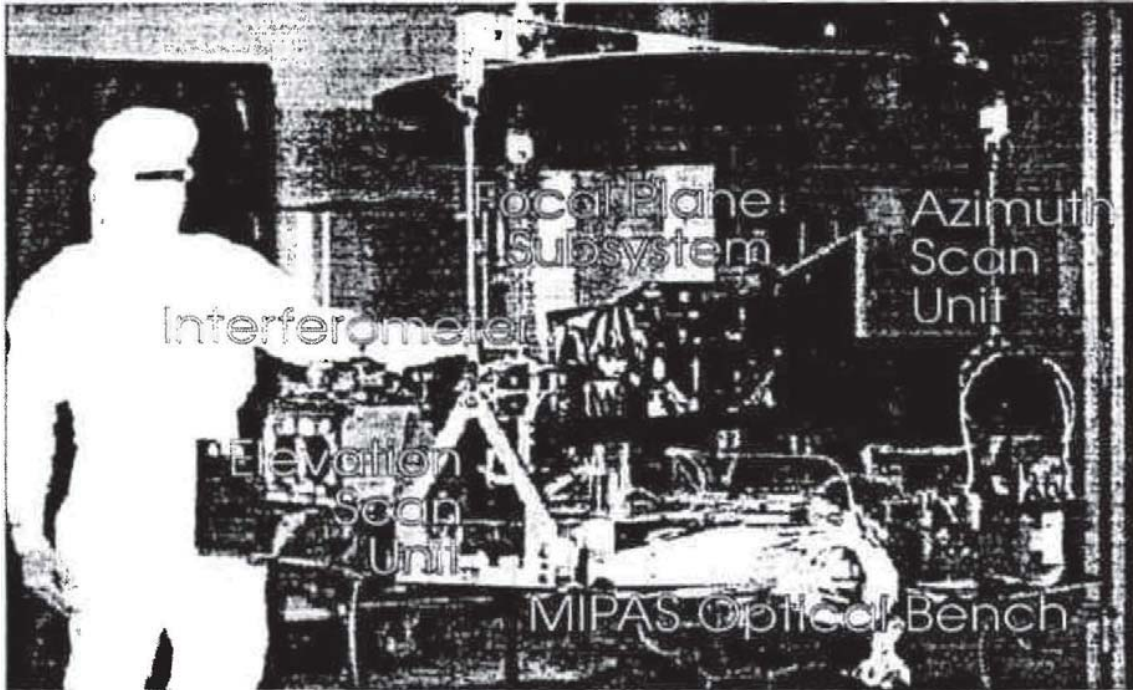


Figure 9 MIPAS optics module during final inspection before closing it with the sidewalls and the radiator on top, as seen from the Nadir side. It shows the arrangement of the scan units and the telescope.

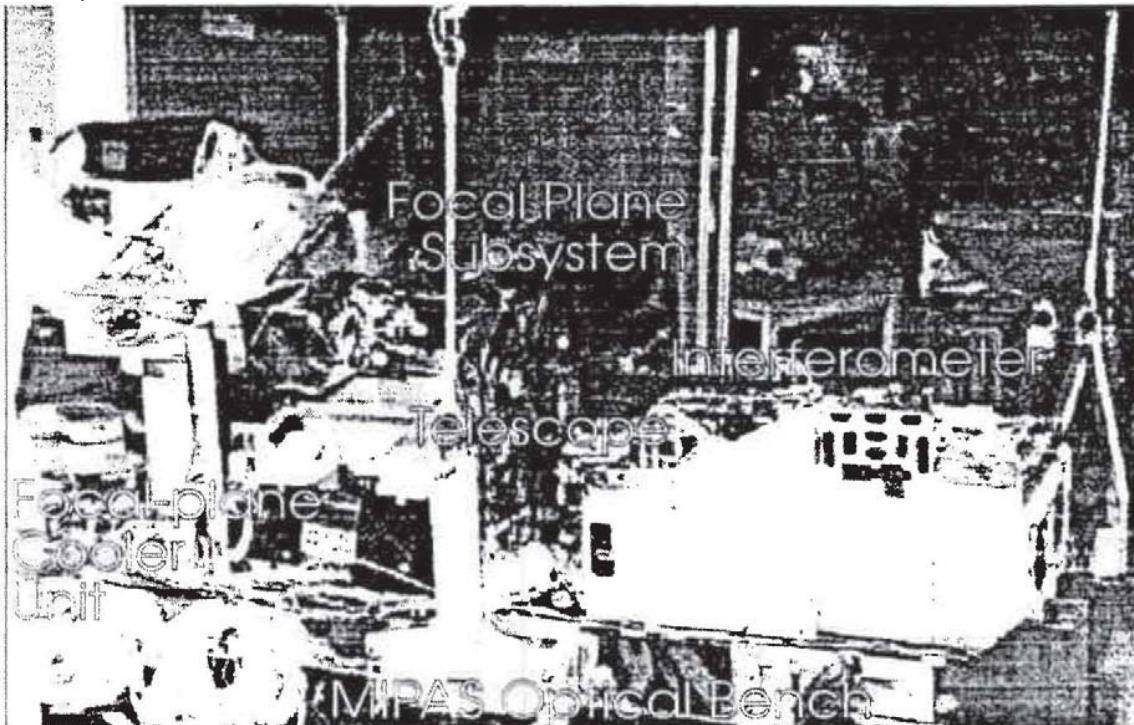


Figure 10 MIPAS optics module as seen from the Zenith side, with the interferometer, focal plane subsystem and the Stirling-cycle coolers visible.

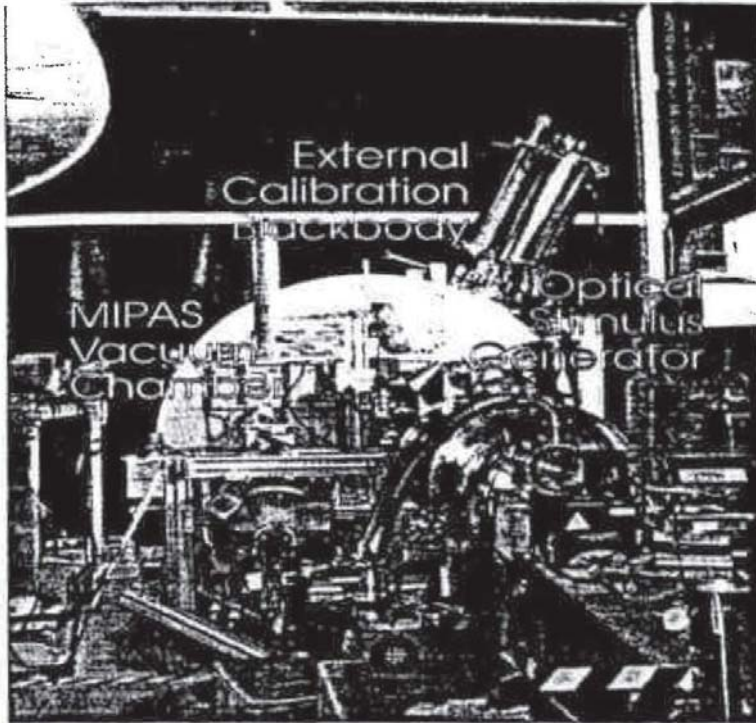
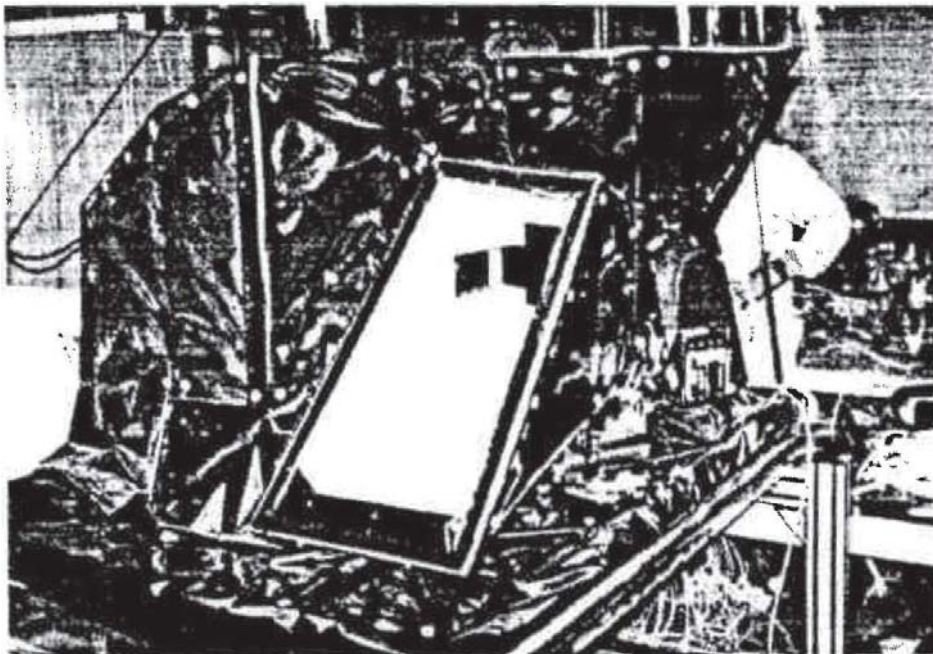


Fig. 11 gives a view of the MIPAS test facility. Testing is quite challenging as MIPAS can only be operated in a thermal vacuum chamber. Thus a dedicated facility was constructed, that allows to cool the optics module to its operating temperature between -70 °C and -40 °C, and to enter the required spectral inputs for full performance verification.

These spectral inputs are generated in the assembly in front of the main vacuum tank. In addition, for verification of the absolute calibration accuracy, a high precision black body is mounted above the MIPAS vacuum chamber to allow viewing through the side baffle.

**Figure 11** View of the dedicated MIPAS thermal vacuum facility with the optical test equipments attached to it: the spectral stimuli are generated by the forward part, while the precision black body is on top of the MIPAS TV-chamber.  
the first thermal and performance testing.

The final picture shows the MIPAS optics module after completed assembly, before integration in the test chamber for



**Figure 12** MIPAS optics module after completed assembly before the first thermal testing. Rearward baffle is in the foreground

## 5 CONCLUSIONS

MIPAS for the ENVISAT-1 mission presents a new type of spaceborne instrumentation that promises to deliver important data about the composition of the middle atmosphere and upper troposphere. It will be the first cooled Fourier transform spectrometer in space and will allow to measure concentration profiles of many trace constituents around the globe, in particular also in the polar regions.

The performance requirements are demanding, in particular the need for high radiometric sensitivity and the radiometric accuracy. The measurements of the actual Flight Model subsystems indicate that the overall performance of MIPAS will meet its requirements. Thus the presented design is considered a good compromise between achievable performance and development risk.

The design has implemented many novel features and solved many challenges, like

- design and qualification of the laser interferometer with the single-mode, polarizing optical fibres and a semi-conductor laser package;
- understanding of potential lifetime limitations of the dry-lubricated interferometer bearings;
- design of an interferometer drive unit which maintains the drive speeds within close tolerances even under varying loads of the interferometer bearings;
- reducing the residual vibrations of the active Stirling coolers transmitted into the Optics Module to avoid generation of spectral ghosts;
- optimizing the mounting of the Optics Modules to the satellite to minimize the heat flux into MIPAS and achieve the design temperature;
- maintaining a contamination control that ensures the required radiometric sensitivity throughout the instrument lifetime

The actual Flight Model hardware is presently being integrated and tested in Munich.

## 6 ACKNOWLEDGMENTS

The design work has been performed by the following industrial team: **Dornier Satelliten Systeme GmbH DSS-FH** (Friedrichshafen, Germany) is the ENVISAT-1 mission prime contractor, and **DSS-OTN** (Ottobrunn, Germany) is the MIPAS instrument prime contractor, with **Bomem** (Quebec, Canada) for support of the system and interferometer engineering tasks;

**Oerlikon Contraves** (Zurich, Switzerland) is responsible for the Front-End Optics with subcontractors **SENER** (Madrid, Spain) for the Azimuth and Elevation Scan Electronics, **SESO** (Aix-en-Provence, France) for the anamorphic telescope, and **AEA-Technology (UK)** for the calibration black body;

**DSS-OTN** is responsible for the Interferometer, which will be realized together with the subcontractors **Officine Galileo** (Florence, Italy) for the mechanism assembly and the drive electronics, **REOSC** (Paris, France) for the interferometer optics, and **Kongsberg Aerospace** (Kongsberg, Norway) for the Laser Interferometer;

**Fokker Space B.V.** (Leiden, Netherlands) is responsible for the Focal Plane Subsystem, with subcontractors **TPD/TNO** (Delft, Netherlands) for the optical design, **GMIRL** (Southampton, UK) for the detectors, and **Com Dev Europe** (Aylesbury, UK) for the preamplifiers; **Matra Marconi Space-Bristol** (Bristol, UK) supplies the Stirling-cycle coolers, and **Rutherford Appleton Laboratories** (Chilton, UK) the low vibration drive electronics;

the Signal Processing Electronics is developed by **Com Dev Canada** (Cambridge, Canada), and the Instrument Control Electronics is designed by **CRISA** (Madrid, Spain), the MIPAS Power Distribution unit by **Delft Sensor Systems** (Delft, Netherlands), and the MIPAS Instrument Harness by **OHB System GmbH** (Bremen, Germany).

**Bomem** (Quebec, Canada) is responsible for the on-ground calibration facilities, and **AFI** (Sollentuna, Sweden) designs the electronic ground support equipment, and **ORS** (Vienna, Austria) supplies the mechanical ground support equipment and the Thermal Control Hardware.