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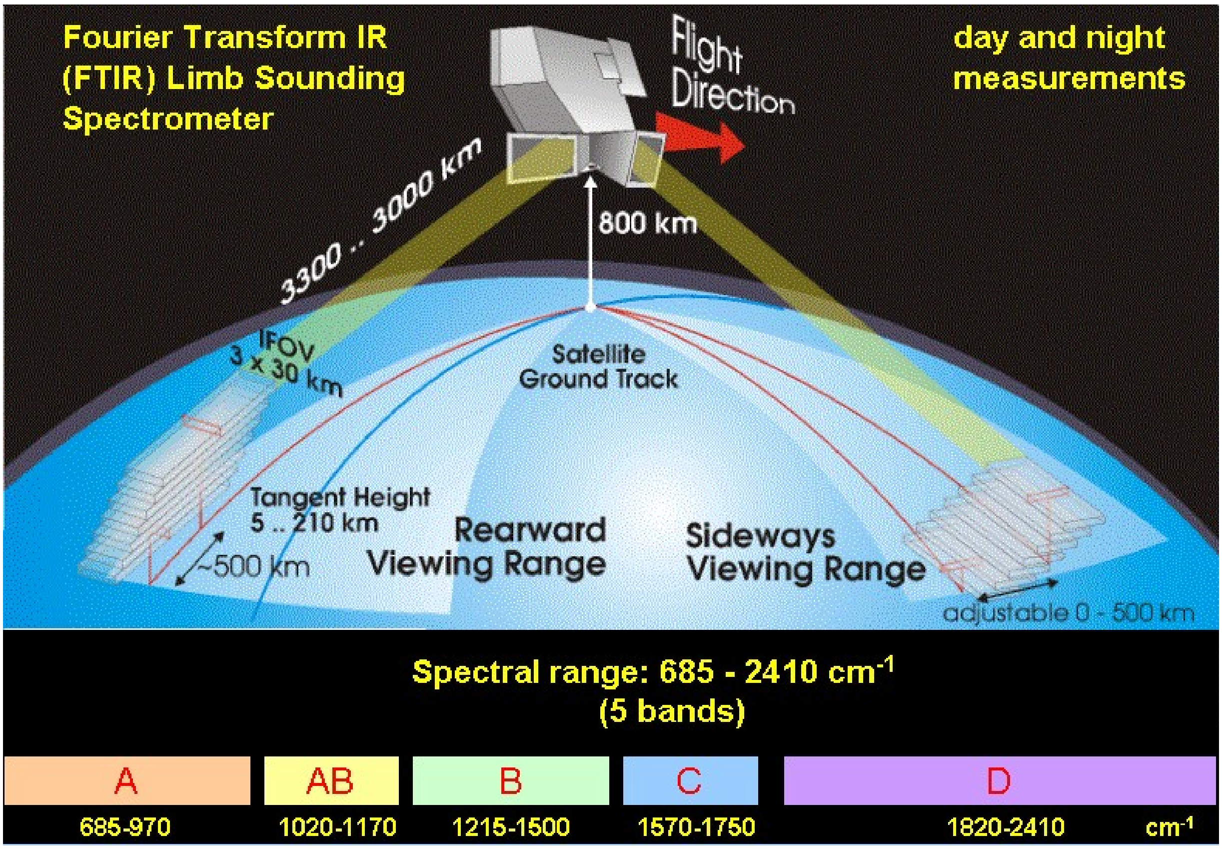
MIPAS Long-Term Calibration and Characterisation Plan



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A P P R O V A L

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1 INTRODUCTION

1.1 Document Purpose

This document describes the rationale, methods and implementation of the long-term calibration and characterisation of the Michelson Interferometer for Passive Atmospheric Sounding (MIPAS) flown on Envisat. Envisat is a European Space Agency (ESA) mission for Earth Observations launched on 1 March 2002. The document contains a brief summary including detailed references of calibration and characterisation activities and results from the Commissioning Phase, and defines the calibration plan for the Envisat Exploitation Phase. In high-level discussions of the combination of calibration, characterisation and verification in this document, this combined set of activities will be referred to as calibration for brevity.

1.2 Document Scope

After the introductory first chapter, the second chapter of this document reproduces the CEOS definitions of fundamental terms relevant to Calibration, Characterisation and Verification, and clarifies their use in this document. Chapter 3 outlines the MIPAS science objectives and introduces instrument and data processing properties relevant for the remainder of the document. Chapters 4 to 6 describe the MIPAS calibration approach, measurements and analysis respectively.

1.3 Acronyms and abbreviations

ACVT	Atmospheric Chemistry Validation Team
ADF	Auxiliary Data File
ADS(R)	Annotation Data Set (Record)
(A)ILS	(Apodised) Instrument Line Shape
ANX (time)	(time of) Ascending Node crossing (intersection of Envisat orbit with x-y plane in Earth fixed coordinate system)
ASAT	Azimuth Start Angle Table
ASU	Azimuth angle Scanning Unit
BB	Blackbody (calibration etc.)
CBB	Calibration Blackbody
CEOS	Committee on Earth-Observation Satellites
CFI	Customer-Furnished Items
CTI	Configurable Transfer Item
DPM/PDL	Detailed Processing Model/Parameter Data List Document
DS	Deep Space (calibration etc.)
DSD	Data Set Descriptor
DSR	Data Set Record
ESACT	Elevation Start Angle Correction Table
ESU	Elevation anlge Scanning Unit

FCE	Interferogram sampling Fringe Count Error
FHPBW	Full Half Power Beam Width
FIR (filter)	Finite Impulse Response (filter)
FOS	Flight Operations Segment
FOV	Instrument Field of View
GADS	Global Annotation Data Set
IECF	Instrument Engineering and Calibration Facility
IGM	Interferogram
IODD	Input / Output Data Definition Document
IPF (MIPAS)	Instrument Processing Facility
LOS	Instrument Line-of-Sight
LRAC	Low Rate Archiving Centre
MCMD	Macro command
MDS(R)	Measurement Data Set (Record)
MICAL	MIPAS Calibration Processor
MJD	Modified Julian Day
ML2PP	MIPAS Level 2 Processor Prototype
MPD	Maximum (optical) Path Difference
MPS	Mission Planning System
MPH	Main Product Header
(non-)LTE	(non-) Local Thermodynamic Equilibrium
NESR	Noise Equivalent Spectral Radiance
NOM	MIPAS measurement mode Nominal activity
NRT	Near Real Time
OM	(Microwindow) Occupation Matrix
p	Atmospheric pressure
(D-)PAC	(German) Processing and Archiving Centre
PAW	(detector) Pre-Amplifier / Warm
PCD	Product Confidence Data
PDHS (-K /-E)	Payload Data Handling Station (-Kiruna / - ESRIN)
PDS	ENVISAT Payload Data Segment
PSM	Parameter Setting Macro command
RGT	ENVISAT Reference operations plan Generation Tool
ROP	ENVISAT Reference Operations Plan
SAIT	(elevation) Scan Angle Increment Table
SBT	Satellite Binary Time
SE (scan, ..)	Special events (scan, ..)
SEM	MIPAS measurement mode Special Events activity
SNR	Signal-to-Noise Ratio
SODAP	Switch On and Data Acquisition Plan
SPH	Specific Product Header
SPE	Signal Processing Electronics
SVD	Singular Value decomposition
T	Atmospheric kinetic Temperature
TBC	To Be Confirmed
TBD	To Be Defined (/Detailed)
TBC	To Be Confirmed
TEP	Test Entry Point
t_{ZPD}	UTC time of interferogram Zero Path Difference crossing

USF	User Service Facility
UTC	Universal Time Correlated
VMR	Atmospheric volume mixing ratio
MW	Microwindow
z	Line-of-sight tangent altitude
ZPD	Interferogram Zero Path Difference

1.4 Applicable Documents

The High-level Operations Plan describes the criteria that are to be used to plan the operations of the Envisat instruments. The MIPAS In-flight Calibration Plan, the Characterisation and Calibration Definition, and the Implementation plan have been generated to define and support the planning and analysis activities of the Commissioning Phase, whereas the CalVal report describes the Commissioning Phase results

The current long-term calibration and characterisation plan is a direct derivation of the inputs and results of the Commissioning Phase, and for that reason frequent reference is made to these documents and where needed descriptions have been reproduced.

[AD1]	ESA/PB-EO/DOSTAG	ENVISAT High Level Operation Plan
[AD2]	PO-PL-DAS-MP-0031	MIPAS In-Flight Calibration Plan
[AD3]	PO-PL-ESA-GS-1124	Implementation of MIPAS Post-Launch Calibration and Validation Tasks
[AD4]	PO-TN-BOM-GS-0013	In-Flight Characterisation and Calibration Definition
[AD5]	PO-TN-BON-GS-0033	MIPAS CALVAL Report
[AD6]	PO-RP-DAS-MP-0024	Instrument Performance Summary
[AD7]	PO-RP-ESA-GS-1369	MIPAS In-Flight LOS Calibration and FOV alignment verification
[AD8]	PO-TN-BOM-MP-0016	Definition of MICAL processing chains
[AD9]		CEOS Cal/Val Newsletter 1

1.5 Reference Documents

[RD1]	ESA SP-1229	MIPAS: An Instrument for Atmospheric Chemistry and Climate Research
[RD2]	PO-PL-BOM-MP-0009	Instrument Level Calibration & Characterisation Plan
[RD3]	PO-ID-DAS-MP-0010	MIPAS Instrument Measurement Data Definition Document
[RD4]	PO-RS-DOR-MP-0001	MIPAS Requirements Specification
[RD5]	PO-TN-DAS-MP-0043	MIPAS Characterisation Data Base
[RD6]	PO-RP-DAS-MP-0024	Instrument Performance Summary
[RD7]	PO-RP-BOM-GS-0003	Detailed Processing Model and Parameter Data List Document (DPM/PDL) for MIPAS Level 1B Processing
[RD8]	PO-TN-BOM-GS-0012	Algorithm Technical Baseline Document (ATBD) for MIPAS Level 1B Processing
[RD9]	PO-TN-DOR-MP-0464	MIPAS Cal/Val Phase procedure inputs
[RD10]		MIPAS Product Handbook
[RD11]	ENVI-SPPA-EOPG-TN-03-0010	Enhanced Analysis of MIPAS Radiometric Performance Using In-Flight Calibration Data
[RD11]	PO-TN-BOM-MP-0019	Non-Linearity Characterization and Correction
[RD12]	PO-TN-BOM-GS-0006	MIPAS In-flight Spectral Calibration and ILS retrieval
[RD13]	PO-TN-DOR-MP-0128	MIPAS LOS Calibration
[RD14]	PO-PL-DOR-MP-0214	MIPAS Switch On and Data Acquisition Plan (SODAP)
[RD15]	190190-PA-NOT-005/6	ENVISAT Instrument Calibration DPM (IECF) Vol. 6: MIPAS

[RD16] 190190-PA-NOT-005/6A ENVISAT Instrument Calibration DPM (IECF) Vol. 6 A: MIPAS Mispointing

2 DEFINITIONS

In agreement with [AD2], [AD3], [AD4] and the CEOS guidelines [e.g. AD9], the following definitions apply.

Accuracy

Accuracy is the absolute uncertainty or error of a measurement result, assuming that the 'true' value of a measurable parameter is known exactly. In general, the accuracy of a measurement is affected by both, random and systematic error sources. In many cases the assignment of accuracies is difficult or even impossible as independent, accurate measurements taken under identical conditions are not available. Often, the accuracy of a measured parameter is estimated through comparisons with other measurements acquired under variable conditions or indirectly, by means of analyses.

Calibration

Calibration is the process of quantitatively defining the system response to known controlled signal inputs. It involves transformation of signals in engineering units into estimates of a physical quantity, expressed in physical units.

Characterisation

Characterisation represents a set of measurements of a specific quantity under well-defined, variable conditions. The purpose of a characterisation is to allow the assignment of an expected result valid at a later instant, given the exact conditions valid at that instant and the results of the characterisation measurements. An example is the characterisation of MIPAS non-linear detector response curves. Here, a detector output is recorded while the irradiance of a target (blackbody source) is varied in a controlled way over a pre-defined range of values (temperatures). The result is used later to correct a measured radiance level (e.g., an unknown scene) for the effect of the non-linear detector response.

Precision

Precision is the uncertainty within which a specific measurement can be reproduced. Assuming that fluctuations in the result of a repeated measurement are of pure random origin, precision is given as the estimated standard deviation (1 s) of the difference (relative or absolute) between individual samples and the average over all measurements.

Verification

Verification is the process of testing a measurement result, an assumption or a functional component through comparison with an expected result or by testing against the performance of a reference component, respectively, making use of a set of pre-defined error margins. The result of verification is always binary, i.e., 'passed' or 'failed'.

In high-level discussions of the combination of calibration, characterisation and verification in this document, this combined set of activities will be referred to as calibration for brevity.

3 THE MIPAS INSTRUMENT

3.1 Scientific Objectives

MIPAS has been developed with the primary objective to enhance understanding of the stratospheric chemistry. Secondary objectives are to study atmospheric dynamics and to observe the upper troposphere, the mesosphere and lower thermosphere. Of particular importance in the lower stratosphere and upper troposphere (UTLS) is the contribution of MIPAS to the study of atmospheric exchange processes between these layers. A full description of the scientific rationale and requirements for the MIPAS instrument is provided in the MIPAS Science Report [RD1]

3.1.1 STRATOSPHERIC CHEMISTRY

by globally observing concentrations of ozone, several species of the nitrogen oxide family, CFCs, carbon monoxide, methane, water vapour, pressure and temperature. The observations cover the stratosphere itself, and for species with appropriate emission signature and concentration also in the mesosphere and upper troposphere. The MIPAS data provide support to process studies (in particular climate-chemistry interactions), model definition and validation, and trend monitoring. For process studies it is essential to monitor production, temporary reservoirs and destruction of active radicals, by observing the radicals themselves together with the species that initiate or stimulate changes in their concentration. The resulting necessity to measure the relevant trace gasses simultaneously, globally (including the important polar regions) and at any time of day and night have been important designs drivers for MIPAS.

3.1.2 ATMOSPHERIC DYNAMICS AND TROPOSPHERIC-STRATOSPHERIC EXCHANGE

An important mission objective for the MIPAS sensor is the study of transport processes, and transient atmospheric disturbances. For this purpose, accurate observations of species that are strongly coupled to advection processes, diurnally varying species and species and geophysical parameters that are relevant for the structure of the atmosphere are required. The observation capability of MIPAS has been designed to allow important contributions. This involves routine observations but also observations in non-nominal modes with increased spatial sampling density, among others around the tropopause.

3.1.3 UPPER TROPOSPHERE

Although important processes occur in this layer, in-situ instruments have sparsely addressed this region. MIPAS has demonstrated its capability to perform observations in this layer in absence of clouds, and is expected to contribute to the study of processes induced by anthropogenic emissions. Aircraft are known to affect the concentrations and reaction rates of species of the nitrogen oxide family and of tropospheric ozone. MIPAS contributes to these studies by its observations of temperature, NO, NO2, O3 and CO in the troposphere.

3.1.4 MESOSPHERE AND LOWER THERMOSPHERE

MIPAS has been designed to contribute to studies of the chemistry, dynamics and the temperature structure of the middle atmosphere. The most important geophysical quantities retrieved by MIPAS in this altitude interval are temperature, and concentrations of water vapour, CO, CH_4, NO, and O_3. MIPAS contributes to the assessment of the energy balance, the study of the upper part of the polar vortices, and is expected to support the investigation of the 'ozone deficit' in the upper stratosphere and lower mesosphere.

3.2 Instrument Description

MIPAS is the first cooled space-borne high-resolution Fourier Transform spectrometer (FTS) conceived for simultaneous observations of atmospheric trace species, with global coverage including the poles, altitude coverage from upper troposphere to lower thermosphere, and coverage of the full diurnal and seasonal cycles. These exceptional capabilities are combined with a high spectral resolution of 0.035 cm-1 wave numbers over a wide range of spectral range in the mid-infrared ranging from 685 to 2410 cm^{-1} equivalent to a range from 4.15 to 14.6 µm resulting in about 60000 independent spectral points per acquisition in high-resolution mode. Detailed descriptions of the MIPAS instrument are provided in [RD1],and [RD10] but the most important features are reproduced here.

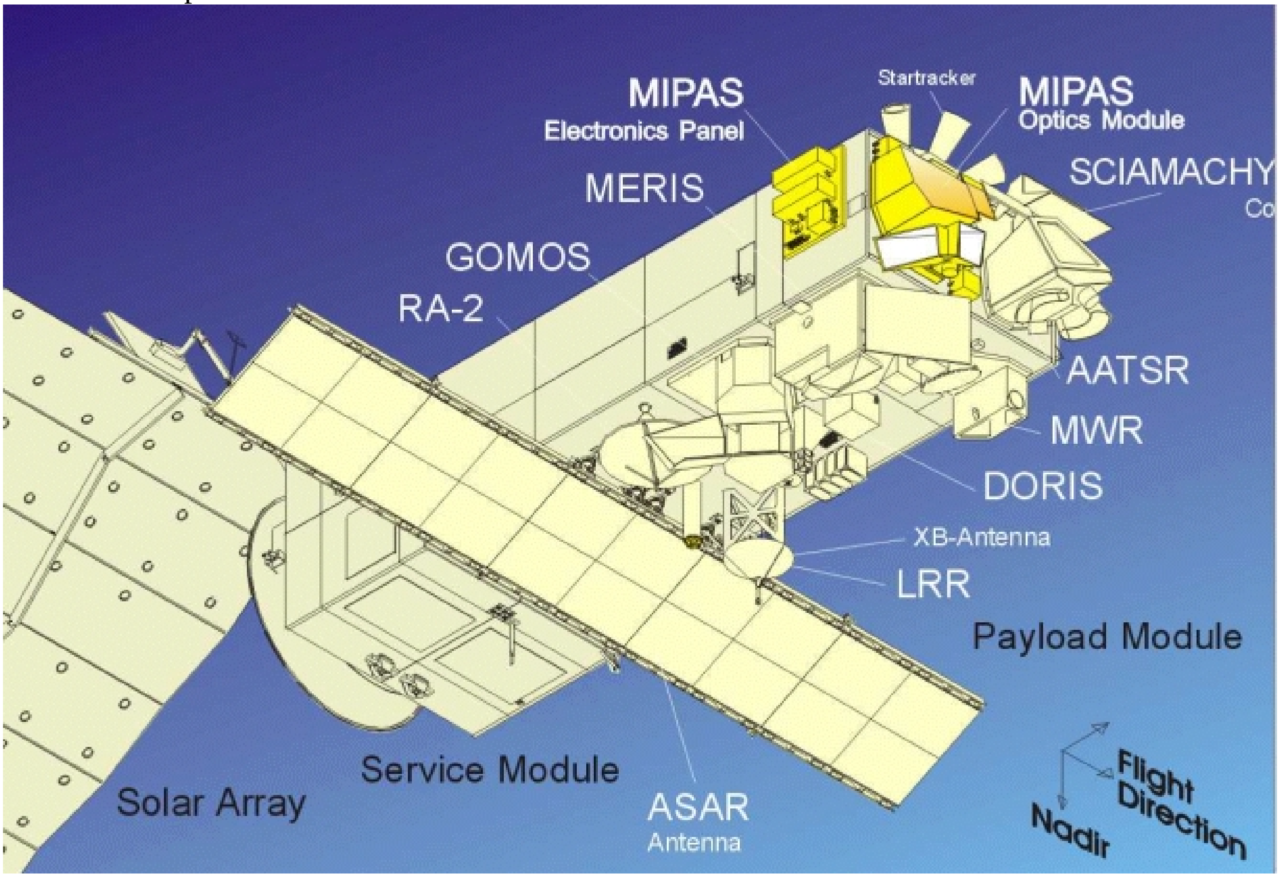

Figure 1: MIPAS on Envisat

The MIPAS flight hardware consists of a Front-End Optics module (FEO), the Michelson interferometer (INT), the Focal-Plane Subsystem (FPS), the Signal Processing Electronics (SPE), and the Instrument-Control Electronics unit (ICE). The optical path is presented in Fig. 2

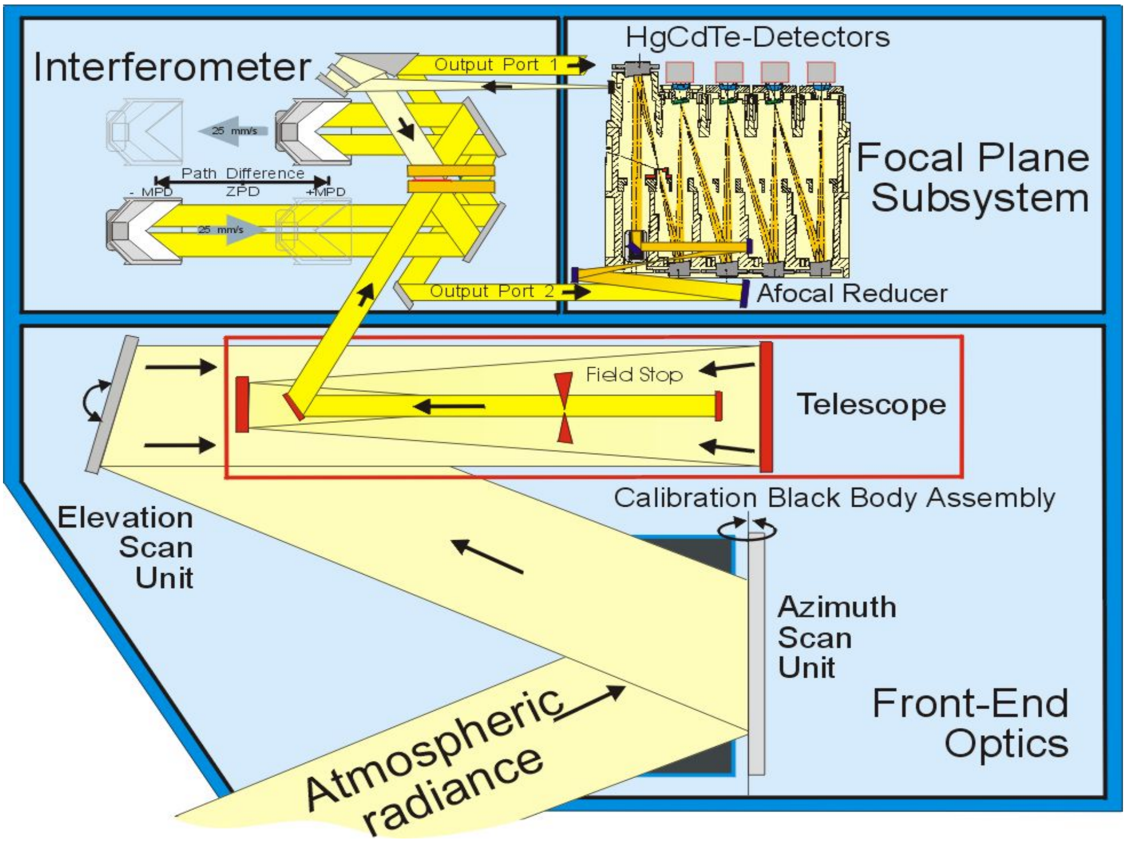

Figure 2. MIPAS Optical modules

3.2.1 FRONT-END OPTICS MODULE

This unit consists of scan mirrors that allow to move the field of view in the azimuth and elevation direction, a telescope (TEL) and a calibration black body assembly (CBA) with thermistors for recording of its temperature. The azimuth mirror allows field of view ranges of 35 degrees around the anti-flight direction, and 30 degrees in the sideways direction (perpendicular towards the flight direction, away from the sun). The elevation mirror allows a field of view range equivalent to a tangent altitude range of 5 to 210 kms. The instantaneous field of view is restricted by a field stop to value of 0.5 degrees in the azimuth direction and 0.05 degrees in the elevation direction, corresponding to 30km in the horizontal and 3 km in the vertical direction at the tangent point of the limb observation.

3.2.2 MICHELSON INTERFEROMETER

The MIPAS interferometer is implemented in the form of a beam splitter that sends the signal received from the front-end optics module towards two retro-reflecting corner cubes. The retro-reflected beams meet again in the beam-splitter and are sent to the focal plane subsystem. Interferograms are obtained by sliding the corner-cubes back and forth along perpendicular paths, resulting in an optical path difference between the two beams prior to their encounter, and hence in phase differences giving rise to an alternating sequence of constructive and destructive interferences as the path difference varies with the linear motion of the cubes. The maximum path difference of 200 mm results in a spectral resolution of 0.035 cm^{-1} and this setting is used for nominal measurement, allowing to acquire a complete interferogram in 4 seconds. Several calibration and special measurements use an operation mode where resolution is reduced by a factor of up to10. An independent laser beam generated by a temperature-stabilised unit is fed into the interferometer to verify the linearity of the motion of the corner cubes (except for the turn-around regions) and to control the sampling of the interferograms.

3.2.3 FOCAL-PLANE SUBSYSTEM

The two output beams from the interferometer (containing the same information) are fed into two telescopes prior to their projection onto the actively-cooled focal-plane subsystem. This consists of 4 detectors per port. To maximise radiometric sensitivity, two Stirling coolers are operated to cool the detector subsystem. The coolers are operated in synchronisation to reduce vibrations. Pre-amplifiers process the output signal of the detectors and pass it to the signal-processing electronics subsystem.

3.2.4 SIGNAL-PROCESSING ELECTRONICS

This subsystem performs several operations onto the outputs of the detectors in order to filter, decimate and reduce word length in order to reduce the data rate to 550 kbits per second, except when the instrument is operated in “raw mode” at 8 Mbits per second. Raw mode is used for a number of special calibration and characterisation measurements, as outlined in later chapters. The readouts of the 8 MIPAS detector channels is combined into 5 bands as follows:

Band	Detector	Decimation Factor	Optical Range [cm^{-1}]
A	A1 & A2	21	685 – 970
AB	B1	36	1020 – 1170
B	B2	22	1215 – 1500
C	C1 & C2	30	1570 – 1750
D	D1 & D2	11	1820 – 2410

The SPE unit can be operated in self-test mode to generate a test signal for input to signal processing in order to verify analog and digital on-board processing.

3.2.5 INSTRUMENT-CONTROL ELECTRONICS

This control unit consists of electronics modules to command and supervise all electronic and mechanical operations of the instrument
.

3.3 Instrument Operations

The MIPAS instrument is operated to perform scientific observations or calibration measurements. Scientific observations can be categorised as nominal measurements, special mode measurements, special events measurements, which are distinguished by spectral and/or spatial resolution and coverage. Note that calibration information is extracted not only from the calibration measurements, but also from the scientific observations as outlined in chapter four.
The measurement principle is presented in Fig. 2, and consists of observations towards the horizon, with successive elevation steps to obtain a vertical profile.

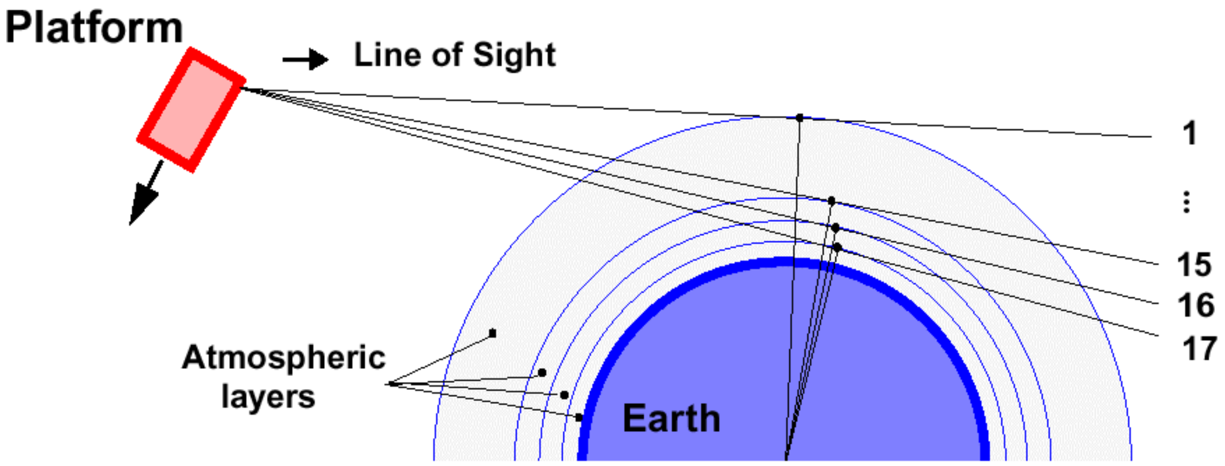

Figure 2: Observation geometry : principle

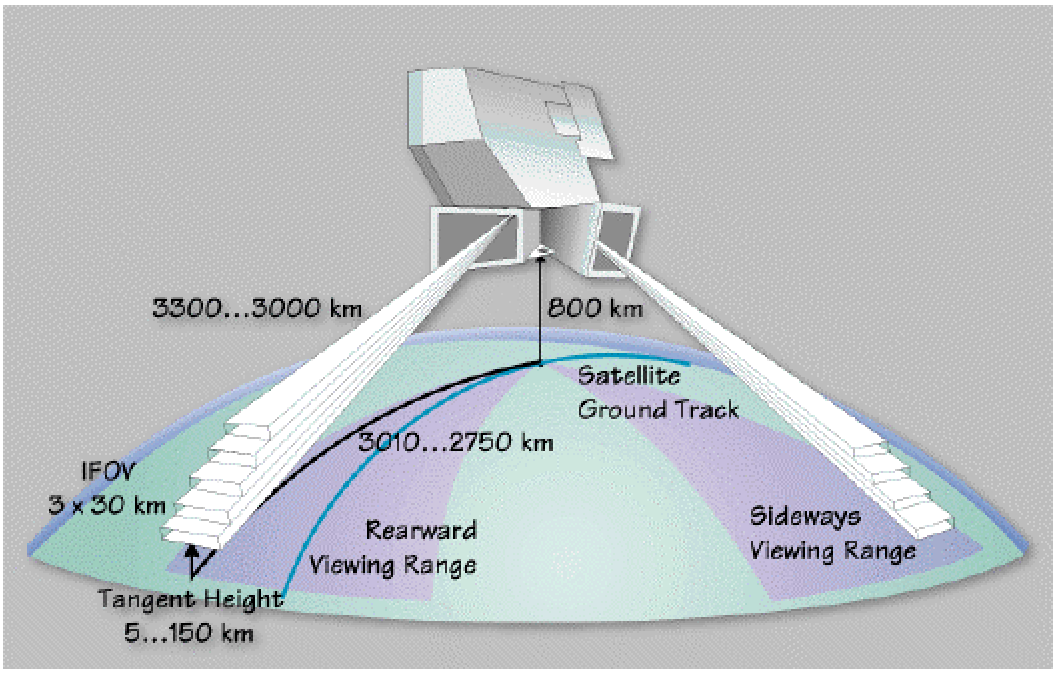

Figure 3: Rearward and sideways geometries

3.3.1 NOMINAL OBSERVATION MODE (NOM)

Most of its mission lifetime, MIPAS will spend in nominal mode. The exact operation properties of nominal mode can be changed in the course of the mission, but currently it can be characterised as:

- 17 Elevation steps at 68,60, 52,47,42,39,36, (3km), 12, 9,6 km
- High spectral resolution
- Rearward viewing geometry
- Global coverage

3.3.2 SPECIAL MODES

Special modes are performed at selected time intervals, and differ from Nominal mode in the aspects outlined below.

3.3.2.1 Polar winter chemistr and dynamics (S1)

- 14 elevation steps 55, 45, 35, 30, then 27 to 13 km in 2km steps, 10, 7
- Global coverage
- Latitude dependent altitude offset following:

Minimum tangent altitude = 8km + 2km*cos(2*tangent point latitude)

3.3.2.2 Troposphere and Tropospheric-Stratospheric Exchange (S2)

- 14 elevations steps 40, 30, 25 km, then 20 to 5 km in 1.5 km steps

- Global coverage

3.3.2.3 Impact of aircraft emissions (S3)

- 11 Elevation steps 40, 30, 23, 18 km, then 15 to 6 km in 1.5 km steps
- Sideways viewing mode
- North of 25 degrees Latitude

3.3.2.4 Stratospheric Dynamics, Transport Processes (S4)

- 15 Elevation steps 53, 47 - 8 km
- 3 azimuth steps at each elevation step
- Spectral resolution reducted by a factor 4
- Global coverage

3.3.2.5 Diurnal Changes (S5)

- 16 Elevation steps from 60 to 15km in 3 km steps
- Spectral resolution reduced by a factor 4
- Near terminator
- Sideways viewing with azimuth adjustment between elevation steps

3.3.2.6 Upper Troposphere / Lower Stratosphere (S6)

- 12 Elevation steps at 35, 28, then 24 to 6km in 2km steps
- Anti-yaw steering azimuth
- Spectral resolution reduced by a factor of 4
- Latitude dependent altitude offset following:

Minimum tangent altitude = 8km + 2km*cos(2*tangent point latitude)

3.3.2.7 Upper Atmosphere Modes

- Non-LTE validation (UA1) from 102 to18 km with step size from 3 to 5 km
- Upper polar vortex dynamics and stratosphere/mesosphere exchange processes (UA2)
- Energy budget, non-LTE studies and budgets of hydrogen, nitrogen and carbon in the upper atmosphere (UA3)
- Non-LTE studies related to NO specifically (UA4)

3.3.3 SPECIAL EVENTS MODE (SEM)

In ‘special events mode’, MIPAS can be operated with alternative choices for the parameters resolution, elevation start and stepping, azimuth start and stepping within the operational constraints of the instrument. This will allow for example to construct a perfectly vertical profile over a target (volcano, validation measurement) in sideways looking mode. Routinely a SEM is performed currently for each orbit in nominal mode, in order to force geolocation of subsequent scans in nominal mode to be performed at a fixed and known latitude grid.

3.3.4 CALIBRATION MODES

In this section, the operational aspects of calibration modes are presented. Further details are found in the next three chapters on calibration approach, planning, and analysis

3.3.4.1 Offset Calibration

This calibration measurement is performed after each set of 5 consecutive normal 'vertical' scans in nominal mode. It consists of 6 observations (interferograms) at 210 km tangent height ('deep space observations'), with a spectral resolution reduced by a factor 10. These observations are performed in order to determine the instrument's self emission.

3.3.4.2 Gain Calibration

This calibration measurement is currently performed once per day, and at each re-activation of the nominal measurement mode. It consists of 6 groups of 100 blackbody observations and deep-space observations each at spectral resolution reduced by a factor 10.

3.3.4.3 Line-of-Sight (LOS) Calibration

As limb viewing sensor, MIPAS is particularly sensitive to correct pointing information, especially in elevation. Scan unit readouts are passed on to the ground processing facility in order to derive tangent altitudes in the processing of level 0 products into level 1 products. The Line-of-Sight calibration consists of a dedicated measurement (currently performed once per week) to assess the accuracy of the pointing thus calculated. This observation involves pointing at fixed elevation in order to observe times of field-of-view entry and exit of selected stars that have sufficient radiance in the spectral window of channel D to be observed by MIPAS. During this observation, the interferometer slides are not moving

3.3.4.4 Special Calibration/Characterisation Operations

All operations below have been performed during the Commissioning Phase, and most activities are included also in the long-term calibration plan. A subset of operations will only need to be repeated in case of significant changes to the instrument.

Code	Description	Operation properties
IF0	LOS characterisation	Routine LOS calibration as described above. Slides fixed, multiple passages per star by overtaking steps between measurements
IF1	On-board Gain settings	Low-resolution blackbody observations (raw mode downlink) combined with high-resolution scene observations.
IF2	Spectral Characterisation	Listed for completeness, but does not involve any special operations. Normal scene data are used for this activity

IF3	Aliassing Verification	100 forward and 100 reverse low-resolution blackbody sweeps in raw mode.
IF4	Non-Linearity Verification	This sequence is modified during the operational phase. During the commissioning phase, it consisted of a sequence of deep-space and blackbody measurements acquired at different temperatures of the blackbody during a gradual heating phase.
IF5	Channel combination verification	100 forward and 100 reverse low-resolution blackbody sweeps downlinked in raw mode
IF6	CBB and DS SNR characterisation	300 forward and 300 reverse low-resolution deep space sweeps, and blackbody sweeps
IF7	Phase Characterisation	This activity has not been performed.
IF8	Radiometric Calibration	Deep-Space and Blackbody observations
IF9	Offset tangent height determination	20 low resolution deep-space sweeps in each direction, at each of 11 altitudes
IF10	$NESR_0$ verification	100 low-resolution and 200 high-resolution deep-space observations
IF11	Absence of high-resolution features verification	100 forward and 100 reverse high-resolution deep-space and blackbody observations
IF14	IFOV Characterisation	Raw measurements, pointing trajectory crossing celestial IR source.
IF16	Raw mode observations	Scene observations at high resolution, but downlinked in raw mode

3.3.4.5 Wear-Control Cycle

Although not a calibration mode, this operation involves interruption of the nominal measurement mode. This mode consists of dedicated operations of the Elevation Scan Unit to avoid uneven wear of its bearings. During WCC the mirror is moved over the entire pointing range in order to distribute lubricant and prevent build up of deposits. In the current baseline, the wear-control cycle is performed once per 5 orbits

3.4 Data Processing and Products

Data acquired by the MIPAS detectors are processed on board, and downlinked to receiving stations on ground. Nominal data and most calibration measurements are stored in level 0 product files of type MIP_NL__0P and handled by the Envisat Payload Data Segment (PDS).
The Line-of-Sight measurements are stored in MIP_LS__0P files and raw data acquisitions in MIP_RW__0P files, and a separate facility dedicated to MIPAS Calibration (IECF/MICAL) handles both these types of files directly, in addition to performing dedicated operations on selected parts of MIP_NL__0P files.

The MIP_NL__0P products fed into the processing chain in the Payload Data Segment are processed into level 1B products: geolocated and calibrated radiance spectra contained in MIP_NL__1P files.
These spectra are produced by applying pointing, radiometric, offset and spectral calibration. Important corrections applied in this process are: fringe-count error correction, spike corrections and filtering, non-linearity correction. In addition, Instrument Line Shape fits are performed and provided in the data product. See [RD7] and [RD8] for a full description of processing steps.

The spectra and auxiliary data are further processed into vertical profiles of trace gasses and atmospheric parameters as described in [RD1]

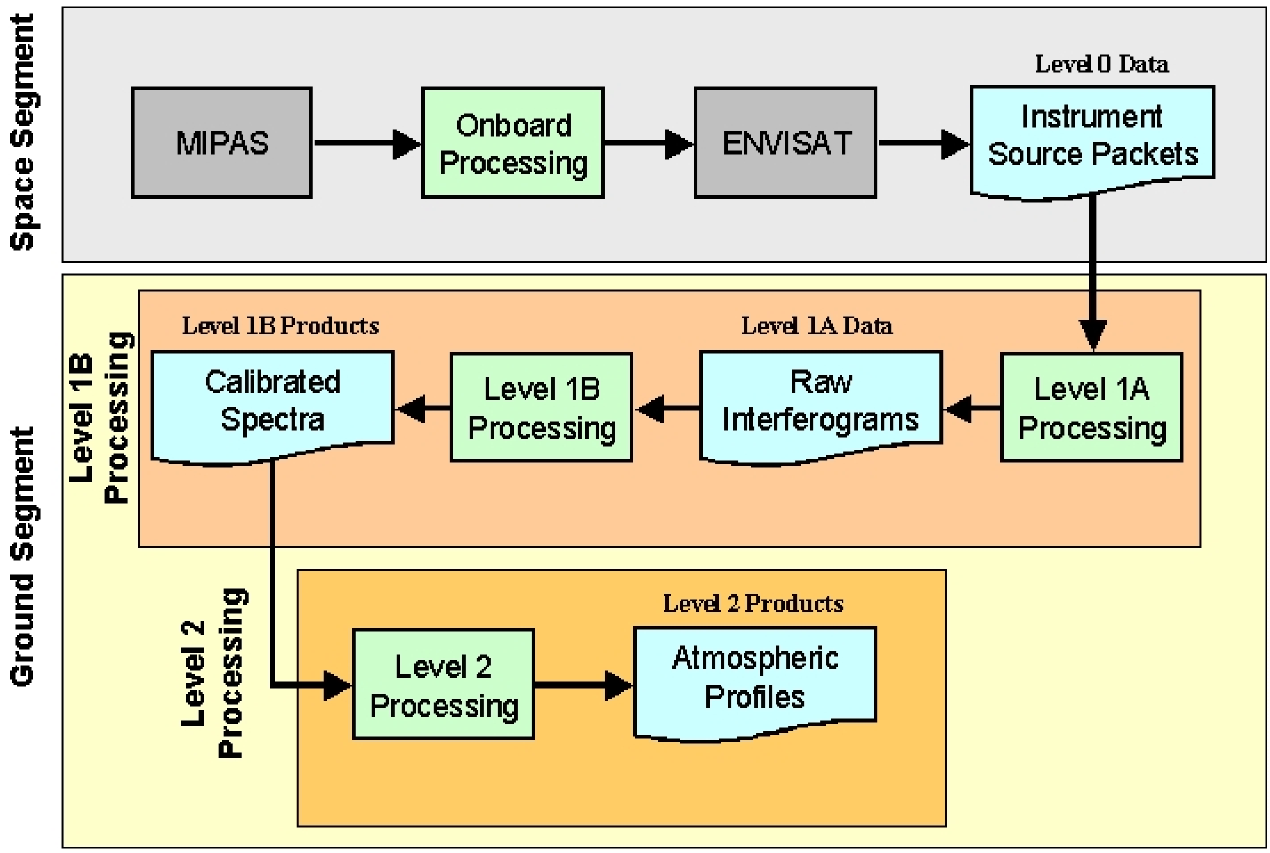

Figure 4: processing sequence

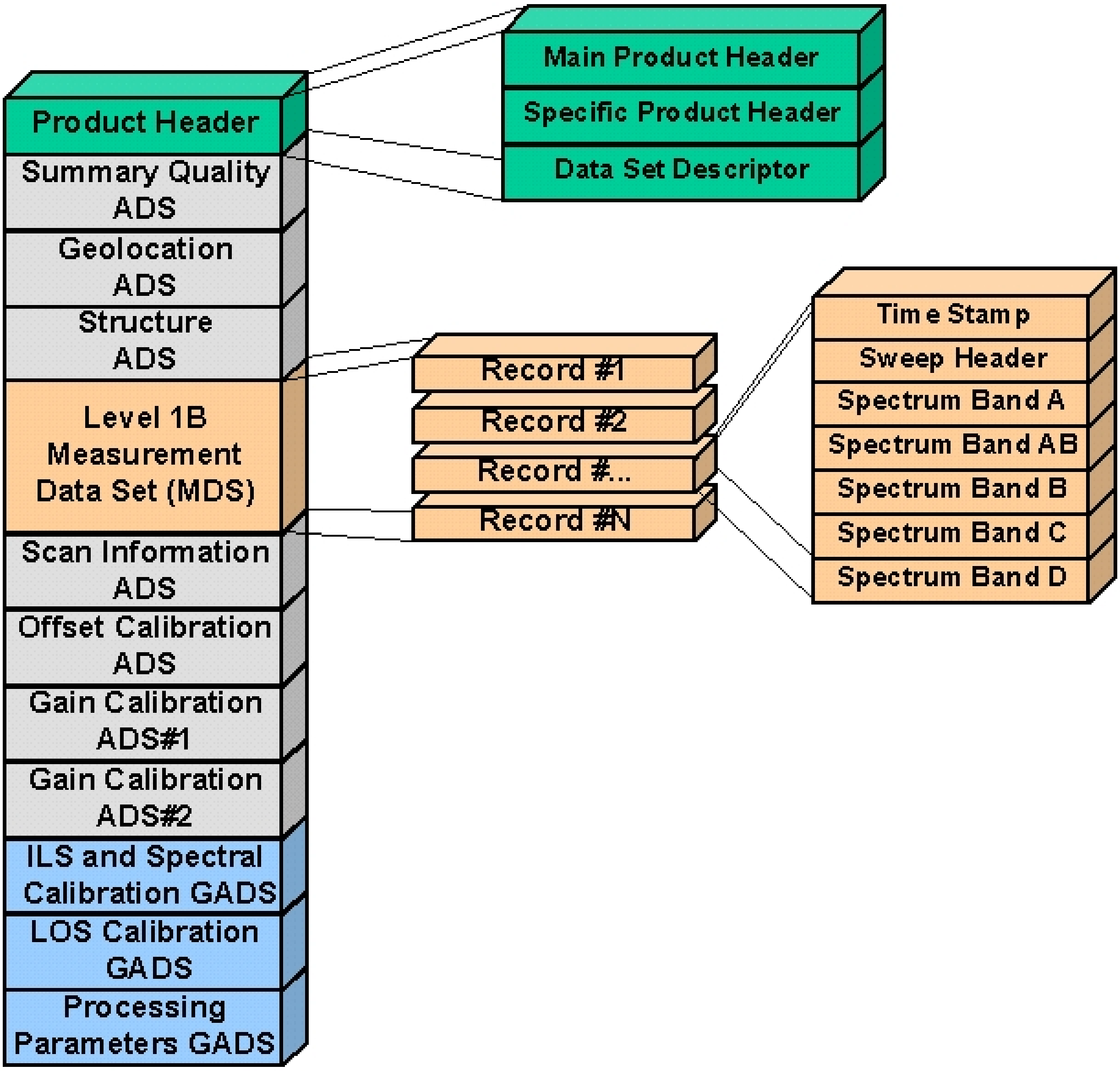

Figure 5: level 1B product structure

4 CALIBRATION OBJECTIVES

The objective of the long-term calibration, characterisation and verification activities is to monitor the behaviour of the MIPAS instrument, assess compliance with requirements and identify deviations, and to ensure correctness of the MIPAS data processing. The calibration activities implemented to reach these objectives are strongly driven by the calibration requirements, which will be discussed in detail in this chapter.

4.1 Calibration Requirements

The calibration requirements provided in [RD6] are derived from scientific requirements. Only compliant pointing, radiometric and spectral accuracy, and spectral range allow retrieval of the MIPAS target species with sufficient accuracy for scientific application.

4.1.1 POINTING REQUIREMENTS

MIPAS observes atmospheric emission in limb-viewing geometry, thus reaching a high vertical resolution whilst collecting radiance from a long optical path. In order to achieve sufficient altitude registration accuracy, the following pointing requirements need to be met:

(R1) The instrument shall be capable to determine the time at which a point source crosses the horizontal centre line of the IFoV to within 80 ms.

(R2) LOS Pointing Knowledge: The instrument shall be capable to calibrate the LOS such that the absolute a posteriori pointing information (end-to-end LOS pointing knowledge), valid at the time of the interferometer ZPD crossing, is better than

(a) 0.032^{o} in elevation wrt F_{MI02}
(b) 0.150^{o} in azimuth wrt F_{MI02}

Further detailed pointing requirements are presented in the table in section 4.3.

4.1.2 RADIOMETRIC ACCURACY REQUIREMENTS

(R1) In the 685 - 1500 cm^{-1} region, the radiometric accuracy shall be equal or better than the sum of $2.NESR_T$ and 5% of the source spectral radiance, using a blackbody with a maximum temperature of 230 K as source.

(R2) In the 1570 - 2410 cm^{-1} region, the radiometric accuracy shall be equal or better than the sum of $2.NESR_T$ and a factor X of the actual source spectral radiance, where the factor X varies linearly from 2% at 1570 cm^{-1} to 3% at 2410 cm^{-1}.

(R3) For temperature variations of the MIPAS instrument corresponding to predicted worst-case orbit variations, the measured spectral radiance shall change less than $2.NESR_T$ + 1% of the source spectral radiance.

Further detailed radiometric requirements are presented in the table in section 4.3.

4.1.3 SPECTRAL CALIBRATION REQUIREMENTS

(R1) The spectral resolution of the instrument shall be better than 0.035 cm -1 which corresponds to a spectral line width of 0.006 nm at a wavelength of 4.15 micron. With this high spectral resolution, MIPAS provides a total of about 60 000 independent spectral samples in each spectrum. A complete high-resolution spectrum is obtained in 4.5 s.

(R2) The spectral stability of the instrument shall be better than 0.001 cm^{-1} during at least 165 s of operation.

Further detailed spectral requirements are presented in the table in section 4.3.

4.1.4 OPERATIONS REQUIREMENTS

The calibration scenario that has been implemented is not only driven by measurement performance requirements but also by operations performance requirements. These are:

<u>Requirements for Nominal Operation</u>

(R1) The instrument shall be able to perform offset calibrations at the beginning of a nominal scan sequence. The repeat cycle between nominal scan sequences and offset calibrations shall be freely commandable

<u>Zero Offset Calibration</u>

(R1) The duration of the Zero-offset calibration measurement including the motion of the azimuth and elevation mirrors from any arbitrary measurement position to cold space calibration position and back to any arbitrary measurement position shall be less than 16.5 s.

(R2) Any offset scenario shall avoid approaching the qualification value for the ESU mirror spindle rotations (7.85 x 10^{6})

<u>Instrument Gain Calibration</u>

(R1) Instrument gain calibration shall on the average use not more than 6% of the overall measurement time during the operational lifetime

<u>LOS Vector Calibration:</u>

(R1) LOS calibration measurements shall on the average use not more than 1% of the overall measurement time during the operational lifetime.

4.2 MIPAS Performance assessment

The following table constructed from [RD6] and [AD5] summarise the performance requirements of the MIPAS instrument, the pre-flight performance and the compliance status at the end of Commissioning.

Performance parameter		Requirement	Pre-Flight	Compliance status
Limb Scan Geometry				
IFOV	Elevation	<0.053°	0.0520°	Ok
	Azimuth	<0.53°	0.513°	Ok
Pointing range	Elevation	113.5° - 117.65°	113.0° –117.7°	Ok
	Azimuth	75° - 110° 30° side	75° - 110° 160° - 190°	Ok
Pointing resolution	Elevation	<0.0086°	0.0021°	Ok
	Azimuth	<0.43°	0.051°	Ok
Line-of-Sight Performance				
LOS Acquisition Accuracy	Elevation	<0.045°	0.032°	Ok
	Azimuth	<0.2°	0.167°	Ok
Pointing Stability 4s	Elevation	<0.0026°	0.00021°	Ok
	Azimuth	<0.13°	0.037°	Ok
Pointing Stability 75s	Elevation	<0.005°	0.003°	Ok
Star crossing knowledge		<80 msec	<30 msec	Ok
Pointing knowledge wrt F_{MI02}	Elevation	<0.032°	0.0032°	Ok
	Azimuth	<0.15°	<0.15°	Ok
Optical Performance				
MTF	Elevation	>80%	87% at 685 cm^{-1} 93% at 2410 cm^{-1}	Ok
Spectral Performance				
Spectral Range		684 – 2410 cm^{-1}	685 – 3000 cm^{-1}	Ok
Spectral Resolution	At 685 cm^{-1}	<0.035 cm^{-1}	0.0303 cm^{-1}	Ok
	At 2410 cm^{-1}	<0.035 cm^{-1}	0.0327 cm^{-1}	
Spectral Linearity	CoG	<0.001 cm^{-1}	0.000062 cm^{-1}	Ok, but eclipse segment to be verified
Spectral Stability		<0.001 cm^{-1}	0.000358 cm^{-1}	Ok, but eclipse

				segment to be verified
Line Shape – Sec Peak	At 685 cm^{-1}	<25%	20.8%	Ok
Line Shape – Area	At 685 cm^{-1}	>70%	86.4%	Ok
Line Shape - Stability	At 2410 cm^{-1}	<0.35 %	0.087%	To be determined
Radiometric Performance				
$NESR_0$ ($nW/cm^2 Srcm^{-1}$)	685-970 cm^{-1}	<50	32	Ok above 700 cm^{-1}
	1020 – 1170 cm^{-1}	<40	19	Ok
	1215 – 1500 cm^{-1}	<20	13	Ok
	1570 – 1750 cm^{-1}	<6	3	Ok
	1750 – 2410 cm^{-1}	<4.2	4.1	Ok below 2220 cm^{-1}
Dynamic Range	Narrow band input	0-250K	Char. Plan	Ok
	Broad band input	0-230K	Char. Plan	Ok
Radiometric Accuracy	685 – 1500 cm^{-1}	<2*$NESR_T$+5% source (70-350)	35-200	Ok
	1570 cm^{-1}	<2* $NESR_T$ +2% source (15)	9	Ok
	2410 cm^{-1}	<2* $NESR_T$ +3% source (16)	6	Ok
Straylight rejection		<50% of $NESR_o$	<50% of $NESR_o$	ok

It should be noted that the Radiometric Accuracy Requirements have been relaxed from their initial value of 2*$NESR_T$ + 1% source after detection of significant non-linearity of the detectors A and B. The radiometric requirements have been relaxed to the values reported in the table, and a non-linearity correction scheme has been incorporated into the data processing chain.

5 CALIBRATION APPROACH

5.1 Calibration Activity Organisation

During the Commissioning Phase, MIPAS calibration has been the responsibility of the MIPAS engineer of ESA/ESTEC's Envisat Systems division (H. Nett). Support has been provided by the MIPAS Instrument Calibration Team (MICT) according to the task organisation and team composition specified in [AD3]

During the Initial Operations Phase and the nominal Exploitation Phase calibration/validation responsibility is transferred ESA/ESRIN's Sensor Performance and Product Assessment (SPPA) section. Specialists from the MIPAS Quality Working Group contribute to the calibration activity, A subset of members performs work on level 2 processor configuration, verification and validation but are also mentioned here as their activity provides feedback on calibration performance.
The composition of the team is as follows:

MIPAS Quality Working Group composition

- ESA/ESRIN
  - SPPA engineer Atmospheric Instruments: R.M. Koopman
  - MIPAS engineer Product Control Facility: R. Mantovani
  - Mission-Planning engineer: M. De Laurentis
- ESA/ESTEC
  - Post-Launch Support Office engineer Atmospheric Instruments: J. Frerick
  - Configuration-Control engineer (2003): J.C. Debruyn
- ESA/ESOC
  - MIPAS engineer Flight Operations Segment: M. Opitz
- Industrial and Scientific Calibration support
  - G. Perron (ABB BOMEM)
  - G. Aubertin (ABB BOMEM)
  - R. Gessner (ASTRIUM)
  - P. Mosner (ASTRIUM)
  - M. Birk (DLR)
  - T. von Clarmann, (IMK)
- Calibration Verification (level 2 team)
  - B. Carli, S. Checcherini, M. Prosperi, P. Raspolini (IFAC)
  - A. Dudhia, V. Jay, A. Burgess, C. Piccolo (Oxford)
  - J. Remedios, R. Spang (Leicester)
  - M. Carlotti (Bologna)
  - M. Lopez-Puertas (IMAAA)
  - B. Dinelli (ISAC)
  - T. von Clarmann, M. Hoepfner, M. Kiefer, G. Stiller (IMK)
  - J.M. Flaud (LPM)
  - S. Bartha (ASTRIUM)

5.2 On-board Calibration

During the commissioning phase optimum values for the following on-board calibration-related settings have been established, via the activities IF1 and IF5:

- Settings for the Pre-Amplifiers, Warm (PAW) Gain for all modes except LOS calibration
- LOS calibration settings for the PAW Gain
- On-board Filtering configuration including Channel-Combination Filter

- LOS pointing settings

The activities and results of the Commissioning Phase are described in [AD2],[AD3],[AD4],[AD5] and [AD7]

During the Exploitation phase, the MIPAS QWG team will verify whether these settings remain adequate and if necessary implement updates into Configurable Transfer Items, to be provided to the Flight Operations Segment for upload to the MIPAS instrument.

5.3 Radiometric Calibration

The radiometric calibration approach is outlined in [AD2], the Commissioning-Phase implementation is described in [AD3] and [AD4] and the Commissioning-Phase results are described in [AD5].

In summary, radiometric calibration is performed to convert the instrument output into spectral radiance (W / cm^2 sr cm^{-1}). The calibration is performed by establishing:

- the instrument output due to its self-emission and
- the proportionality factor between output and radiance.

The self-emission is measured during the Offset Calibration, and the proportionality factor during the Gain calibration.

Offset calibration measurements consist of observations of deep, acquired by pointing the elevation mirror to 23 degrees of elevation. Gain calibration measurements consists of observations of the on-board calibration blackbody, and are acquired by pointing the elevation unit to 23 degrees and the azimuth mirror to 270 degrees.

Offset calibration measurements and data processing is performed on timescales at which the instrument temperature varies, gain calibration measurements and data processing is performed in the at timescales at which evolution of the throughput of the optical and electronic subsystems varies. These timescales are discussed in the next chapter. Currently, offset calibration data processing is performed by the Payload Data Segment, whereas gain calibration data processing is performed by the independent calibration chain (MICAL) incorporated in the Instrument Engineering and Calibration Facility (IECF).

During calibration, consistent handling of the phase characteristics of the measurements is performed by correcting for phase jumps due to lost fringes in the fringe counting system, and by processing independently observations taken during forward and reverse motion of the interferometer.

In response to the observed non-linearity of the output of the A and B detectors as a function of incident radiance, a non-linearity calibration has been implemented.

The implementation of this high-level approach is detailed in the following sections.

5.3.1 OFFSET CALIBRATION

In order to reduce the time spent performing offset calibration measurements, they are performed at low spectral resolution. Although the offset calibration is performed, processed and applied routinely in the processing chain, the following verifications and optimisations are performed separately, in order to ensure that the routine calibration remains optimised.

Absence of high-resolution features verification ("IF11")
During commissioning, this verification demonstrated the absence of high-resolution features, so that the low-resolution measurements, after phase correction, can be used to correct the high-resolution scene measurements. The IF11 verification is repeated during the Exploitation Phase to assess continued validity of the assumption of absence of high-resolution features.

Minimum offset tangent height determination ("IF9")
In order to maximise life time of the Elevation Scan Unit lead screw, offset measurements are performed at low tangent altitudes within the range of altitudes where atmospheric emissions are demonstrated to be absent. During commissioning, the activity IF9 demonstrated that atmospheric features are absent above 191 km. The IF9 verification is repeated during the Exploitation Phase to ensure the lowest possible tangent height is used. This altitude could potentially change for example due to instrument sensitivity degradation.

The transition from the altitude and resolution of the nominal mode to the higher altitude and lower resolution of the offset calibration takes 5.7 seconds. The measurement itself consists of 3 forward and 3 reverse sweeps lasting 0.4 seconds each. The total interruption of scene measurements due to offset calibration thus amounts to 16.15 seconds per offset sequence.

5.3.2 RADIOMETRIC GAIN CALIBRATION

A radiometric gain calibration is a combination of blackbody observations preceded by dedicated deep space observations to allow offset correction. All observations are made at low spectral resolution in order to obtain a large number of measurements without excessive interruption of measurement time. This large number of measurements is required in order to achieve a sufficiently high signal-to-noise ratio through co-addition, especially in band D. As can be seen from Fig.7 significant changes in gain are observed during the mission, as a consequence of on-board contamination.

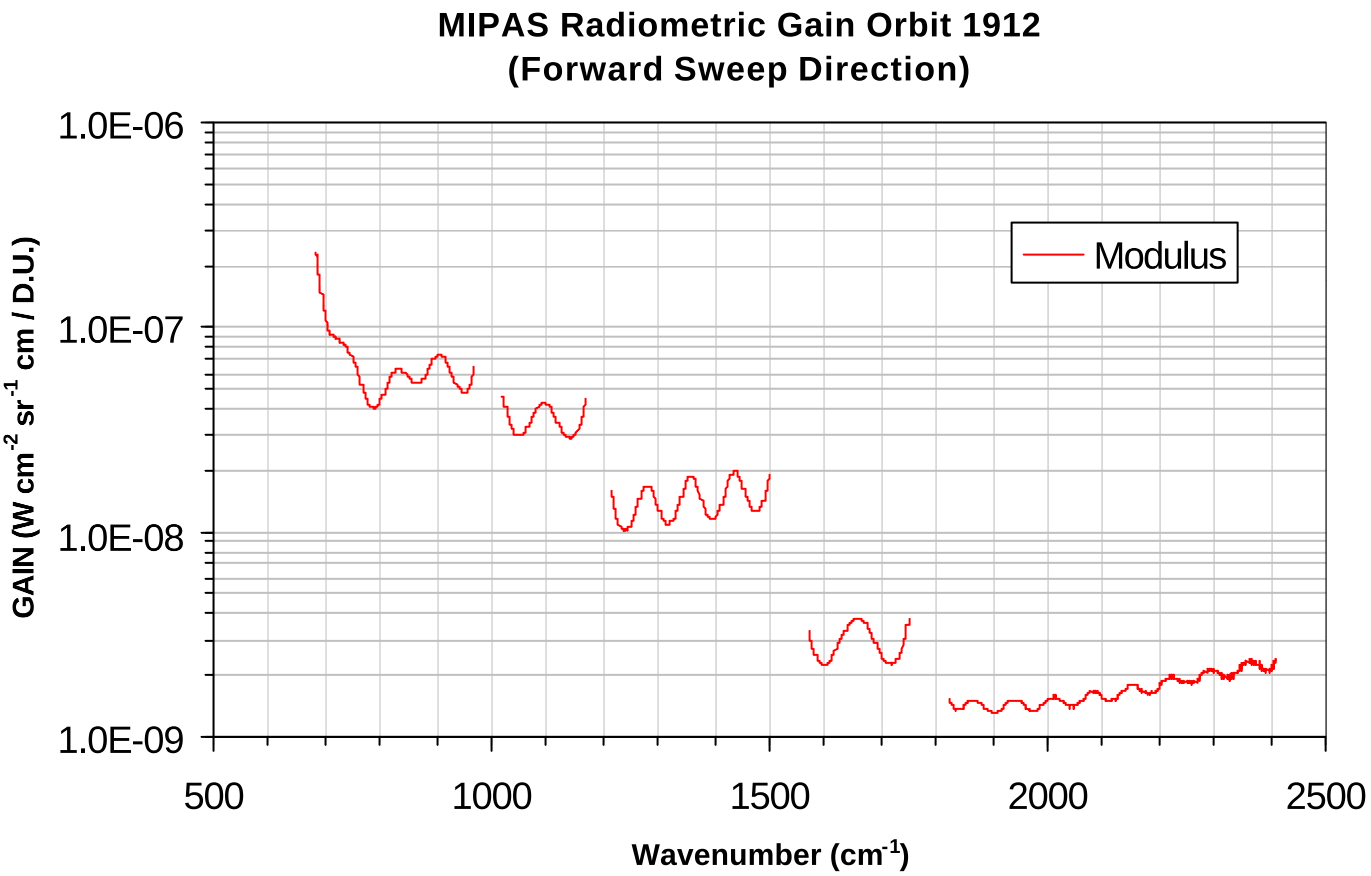

Figure 6. MIPAS radiometric gain characterisation

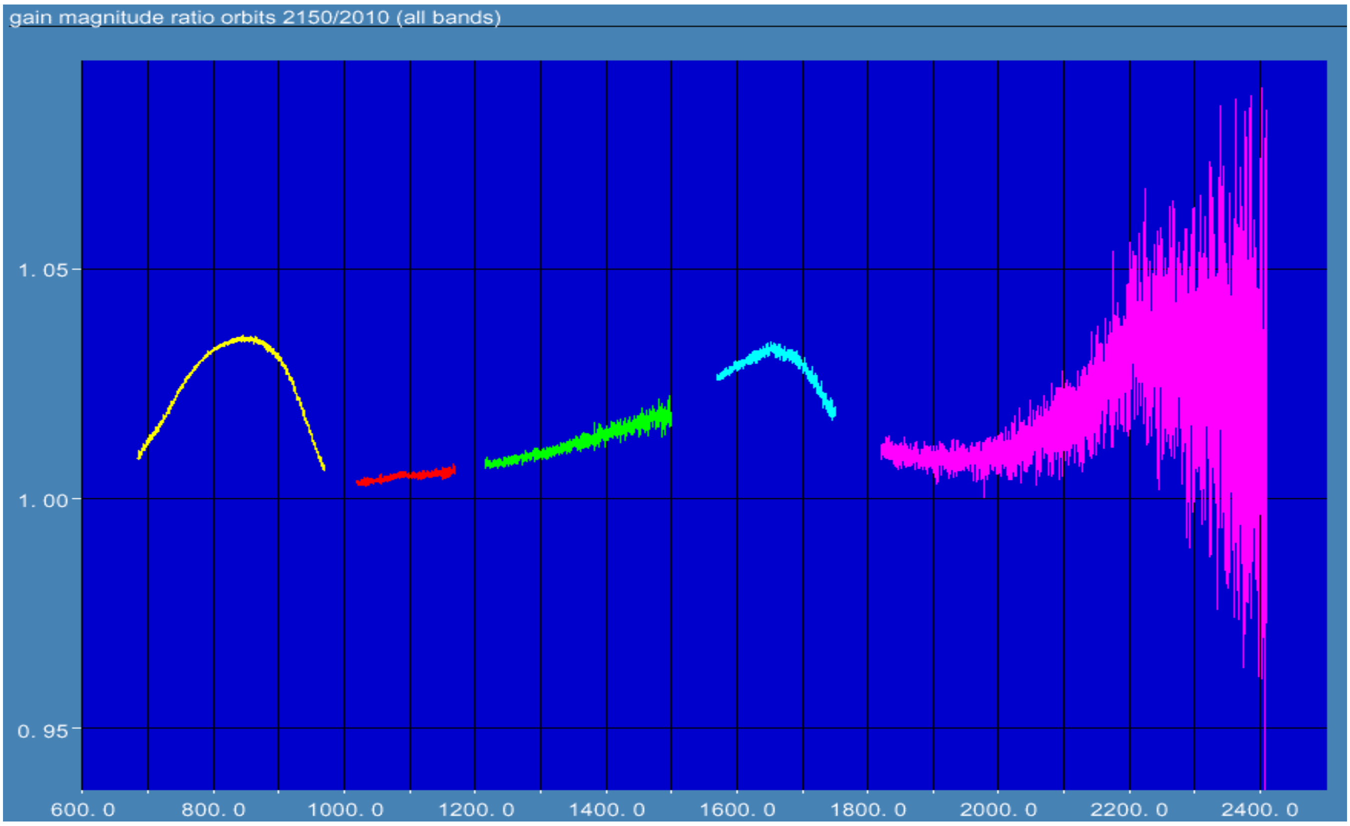

Figure 7. Observed gain changes over a 10 day period

Although the gain calibration is performed, processed and applied routinely in the processing chain, several verifications and optimisations are performed separately, in order to ensure that the routine calibration remains optimised.

Characterisation of radiometric errors due to aliassing ("IF3")

The on-board numerical filter is optimised for a single frequency of the laser that is used to derive the optical path difference. As a consequence any drift in the laser frequency translates into a radiometric error. The characterisation is performed by a dedicated verification activity performed with the independent calibration chain, and requiring dedicated data acquisition. For this verification interferogrammes are acquired in raw mode, and subsequently the same filtering and decimation operations that would have been performed in the instrument in nominal mode are applied on ground, and the result is compared to the original raw mode spectrum to assess the radiometric differences and compare to the aliassing radiometric error budget of 0.001. Generally no significant aliassing was found except for a distinct spike due to incomplete DC signal removal by the on-board filter which is now removed in on-ground processing, and a feature in band D due to folding of signal at wave numbers higher than 3803 cm-1 into the band D signal.

Non-linearity Characterisation ("IF16-IF4-IF16")
During the Commissioning Phase a non-linearity verification has been performed consisting of commanding the calibration blackbody through its entire temperature range up to its maximum temperature of 248 K. During the temperature changes, blackbody observations are performed at different blackbody temperatures (229, 234, 236, 240, 246) combined with sequences of deep-space measurements to correct for offset. The known blackbody temperatures allow to derive the ratios between the input radiances, and these are compared to the ratios of the output signals to identify non-linearity. Commissioning-Phase results have shown that the lowest blackbody temperature is too high to allow full characterisations of the non-linearity for low fluxes, and for that reason an extended characterisation is under assessment. This characterisation, described in [RD11], involves minimisation of out-of-band spectral contributions of raw mode low-flux scene measurements ("IF16") to extend the non-linearity curve obtained from the "IF4" measurements.

Channel Combination Characterisation ("IF5")
In on-board processing, the detector signals of three pairs of detectors A1 and A2 , C1 and C2, D1 and D2 are combined into the three bands A, C, and D. The signal of the first detector of a pair is multiplied with a wave number-dependent equalisation vector prior to combination. This vector is chosen to maximise the signal-to-noise ratio of the combined signal. Low-resolution blackbody spectra are downlinked in raw mode (and corrected for non-linearity in the case of detectors A1 and A2) and average signal and noise are calculated for each detector, in order to derive the optimum equalisation vector. Only in case this vector deviates by more than 5% from the vector applied on-board, the latter shall be updated.

CBB and DS Signal-to-Noise characterisation ("IF6")
This characterisation is performed to assess the optimum number of sweeps of blackbody and deep-space observations for the operational gain calibration within the overall budget of 12 sweeps (600 forward, 600 reverse). The optimum ratio of Blackbody vs. deep-space sweeps is derived from the ratio of the noise values.
The commissioning-phase assessment has shown a combination of 710 blackbody and 490 deep-space observations to give the best SNR. Currently the original baseline of 600 each is maintained but the QWG will re-assess this baseline.

Phase characterisation ("IF7")
This verification consists of assessment of phase changes between successive blackbody and deep space measurements. It has not been performed during the Commissioning Phase.

Radiometric Gain Characterisation ("IF8")

This verification consists of a modified gain scenario where the number of sweeps is reduced by a factor four compared to the operational scenario, in order to perform 24 gain sequences in one orbit per day for 15 days. This verification has not been performed during the Commissioning Phase, but instead a longer time series of nominal Gain calibrations have been performed. From the evolution of the gain due to deposition of contamination on the detectors during the Commissioning Phase, it has been derived that gain calibration must be performed at least once per 10 days. During the Exploitation Phase the routine gain measurements are analysed regularly to review the gain parameter update frequency, and also the gain calibration measurement frequency, in response to changes in the evolution of the gain.

$NESR_0$ verification ("IF10")

This verification is performed by applying radiometric calibration to high and low-resolution deep space spectra and calculating the standard deviation. For low-resolution spectra, full compliance has been observed whereas for high-resolution spectra NESR0 above specification has been observed for wave numbers below 730 cm^{-1} and above 2190 cm^{-1}.

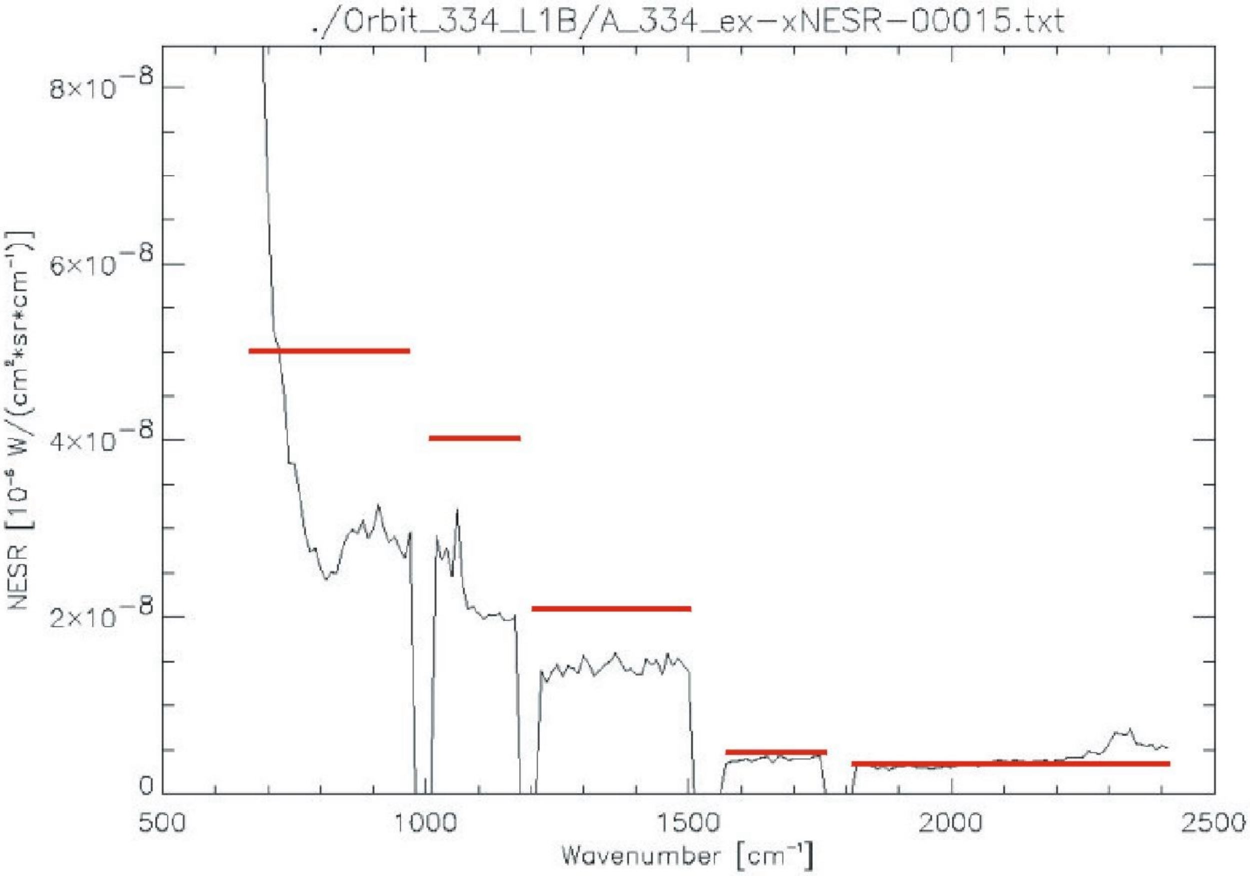

Figure 8: $NESR_0$ requirements and performance

Absence of high-resolution features verification ("IF11")

Exactly the same approach is used as described under Offset Calibration.

ASU Mirror Responsivity assessment

According to [AD2] it has been established that the reflectivity of the ASU mirror as a function of incidence angle vary less than 0.14% in the relevant wavelength range, and no compensation is necessary, in contrast to optical space-borne sensors with mirrors.

Characterisation of CBE performance

If the CBB read out electronics (CBE), which measures the resistance and assigns an associated digital value through an ADC, were unvarying in performance, then there would be no need for additional measurements during flight over and above the actual PRT readings themselves. However, some change in the CBE performance is expected with time & temperature, which means that it will be necessary to recalibrate the relationship between the digital read-out from the CBE and the actual

resistance of the PRTs themselves. (The PRTs are highly stable and precise, hence it may be assumed that their resistance-temperature relationships can be characterised on ground and will remain constant during flight.) For this re-calibration, the CBE digital read-out corresponding to a precisely known resistance is needed, which is achieved by cycling round a dedicated set of precision resistors in the CBB and sending the measurements as part of the auxiliary data stream.
This downlink is performed at every radiometric calibration, and the results are inserted into the ground-segment algorithm that converts the ADC values into resistance. Following this self calibration, all subsequent ADC read outs from the CBE are converted to resistances using the new coefficients. Ground correction using coefficients derived via the characterisation approach achieves an accuracy well inside the allocated radiometric accuracy contribution, even under worst case assumptions.

5.4 Spectral Calibration

Spectral calibration is performed by the operational ground segment by comparing the data point index of spectral lines in scene observations with the known wavelength of these lines. High-resolution scene interferograms are corrected for offset, Fourier transformed and zero padded, and the real part is extracted to produce uncalibrated emission spectra and finally spectral axis assignment is performed by comparing lines of known frequency to the uncalibrated spectra.

Although the spectral calibration is performed, processed and applied routinely in the processing chain, several verifications and optimisations are performed separately, in order to ensure that the routine calibration remains optimised

Short-term spectral stability (“IF2a”)
A set of spectral axis assignments from successive wavelength calibrations (8 successive orbits) has been compared during the Commissioning Phase for assessment of short-term stability. Although generally compliant with the requirement of < 0.001 cm^{-1} a worst case of 0.0028 cm^{-1} has been observed. During the Exploitation phase this verification, and all verifications below, will be repeated at regular intervals.
Long-term spectral stability (“IF2b”)
In this case the observation set is co-added prior to processing in order to obtain a measure of long-term stability. The Commissioning-Phase result of 0.0005 cm^{-1} is well within the requirement of <0.001 cm^{-1}.
Spectral Linearity (“IF2c”)
This verification is performed on the spectral axis assignment results of individual wavelength calibrations. Although generally compliant with the requirement of < 0.001 cm^{-1}, a worst-case Commissioning-Phase result of 0.032 cm^{-1} has been observed.
Spectral Resolution (“IF2d”)

This verification of the width of Instrument Line Shape (ILS) is performed by comparing the shape of the highest-frequency peak with the MIPAS ILS model applied to the best knowledge of the actual line shape (spectroscopic database). Although generally compliant with the requirement of < 0.035 cm^{-1}, a worst-case Commissioning-Phase result of 0.047 cm^{-1} has been observed.

5.5 Geometric Calibration

5.5.1 LINE-OF-SIGHT CALIBRATION

An important calibration step is the assignment of the tangent altitude to the observed emission spectrum. This assignment is based on instrument pointing. Errors in pointing knowledge can originate from the instrument (internal alignment), the platform (pointing accuracy), and the interface between platform and instrument (thermal deformation, launch impact).
Line-of-sight pointing requirements consist of the a priori pointing acquisition accuracy and the a posteriori pointing knowledge. Pointing errors can be characterised in terms of static bias terms, uni-directional drift terms, harmonic terms, and random errors.

The operational LOS measurements are performed to quantify the a posteriori pointing knowledge errors, and calculate an appropriate correction for instrument commanding and/or data processing. This calibration is performed by operating the instrument with the interferometer corner cubes in fixed position at their end positions (to ensure that vibrations that could affect the signal are minimal) and by pointing the IFOV at fixed elevation chosen to ensure that selected stars cross the field-of-view. The times of entry and exit of the field-of-view are retrieved from the specially processed output of the D channels and compared to predictions based on the known position of the star and the platform, in order to retrieve the exact orientation of the line-of-sight, and calculate mispointing characterisation parameters (bias and harmonic terms for the pitch and roll axes). These values are provided to the data processing chain for correction, and if needed a correction is uploaded to the instrument to improve commanded pointing angles.

5.5.2 IFOV CHARACTERISATION

In view of the invalidity of on-ground IFOV characterisation results, an in-flight characterisation method has been devised during the Commissioning Phase. This method consists of active scanning in the elevation direction of the field-of-view across a bright infra-red source. The planet Mercury was selected during this first in-flight IFOV characterisation, and Mars and Venus are alternative targets meeting IR signal requirements. Signals from all 8 detectors are recorded with the interferometer operating in high and low-resolution mode, and data downlink is performed in raw mode. Two special events are commanded on either side of the target in order to force a scanning motion across the target during the transition sweep of the second special event sequence.

6 CALIBRATION DATA PROCESSING

6.1 Processing by the Payload data segment

The calibration data processing performed in the operational data processing chain is described in detail in [RD7] and [RD8].

The radiometric calibration involves the following sequences:

Offset Calibration:

i) Separate forward & reverse sweeps
ii) Detect & correct any fringe count errors
iii) Co-add vectors of same type
iv) Scale offset vector for PAW gain (if required - see Section 5.2.2.4.2)
v) Scale offset vector for DPU responsivity at time of measurement
vi) Correct for detector non-linearity
vii) Equalise & combine A channels

Gain Calibration:

i) Separate deep space, CBB gain, forward & reverse sweep types
ii) Compare gain vectors to previous gain for spectral shift & correct if necessary
iii) Detect & correct for any fringe count errors
iv) Co-add vectors of same type
v) Scale gain vector for PAW gain and/or orbit variations
vi) Scale gain vector for DPU responsivity at time of measurement
vii) Correct for detector non-linearity
viii) Perform offset subtraction
ix) Equalise & combine A channels (if not already performed on-board)
x) Generate gain spectrum, interpolated to correct axis
xi) Compare with expected spectrum (template)
xii) Calculate blackbody radiance spectrum
xiii) Scale gain vector using blackbody spectrum

Scene Measurements:

i) Detect & correct any fringe count errors

ii) Scale gain vector for DPU responsivity at time of measurement
iii) Correct for detector non-linearity
iv) Equalise & combine A channels
v) Subtract appropriate offset vector
vi) Generate scene spectrum, interpolated to correct axis
vii) Perform radiometric calibration of scene by multiplying with appropriate gain vector

The spectral calibration processing is separated in two distinct purposes:

- Processing of selected calibrated spectra for the generation of a spectral calibration table

- Processing to spectrally calibrate a spectrum, i.e. to perform the wave number assignment of the spectral scale using the derived calibration table. This is done via a spectral interpolation on a predefined spectral axis.

The processing for the generation of the spectral calibration table requires the following functional steps

- Define the spectral window containing the reference spectral line. This is done using the current spectral calibration.

- Find the peak corresponding to the reference spectral line within the spectral window of the appropriate band.

- Define the new spectral axis (assignment of wavenumbers throughout a spectral band) for each band and each possible setting of resolution and decimation.

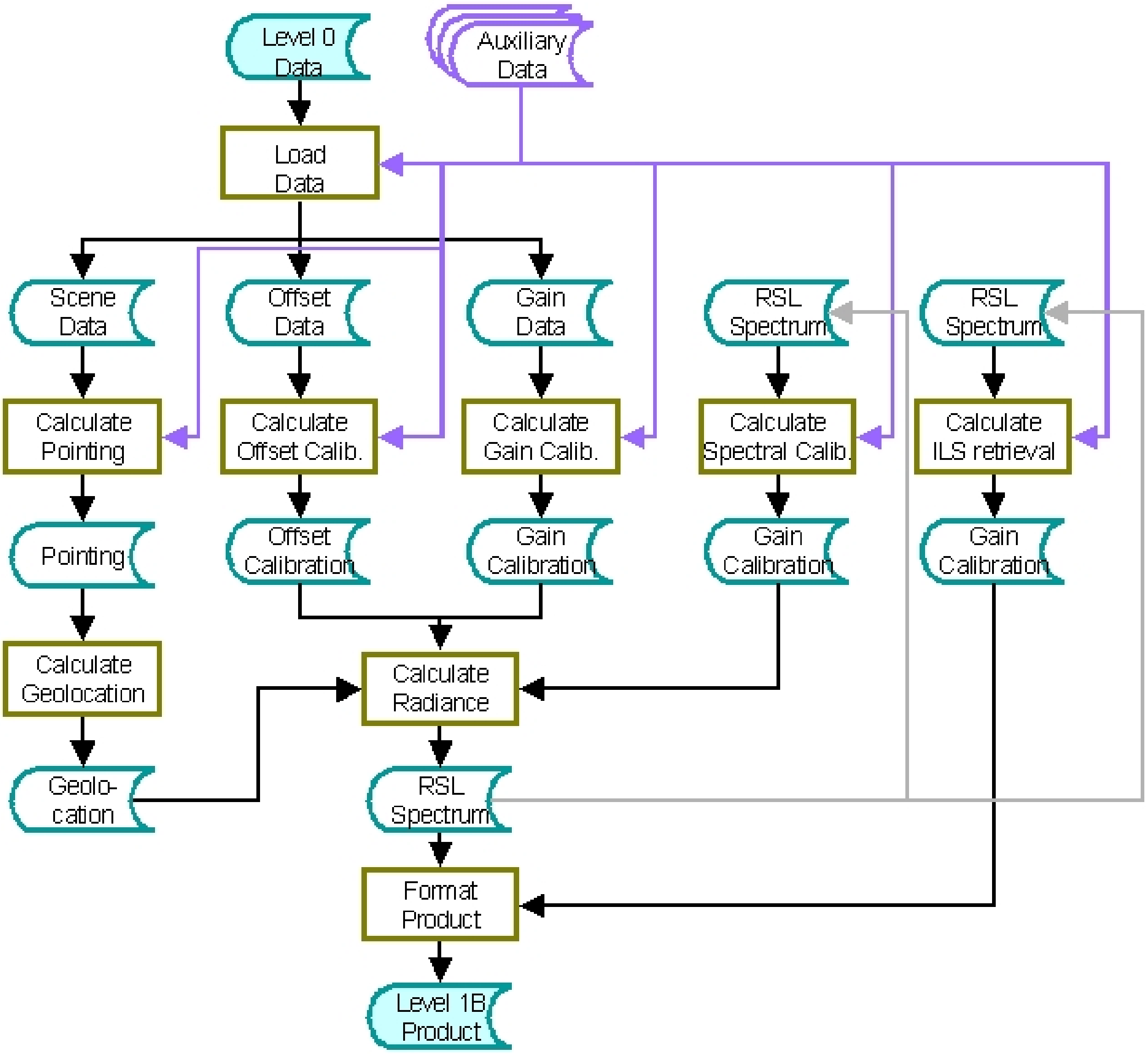

Figure 9: Level 1B ground processing chain

6.2 Processing by the Calibration Facility

The independent calibration facility is used to routinely process the following calibration and characterisation measurements:

6.2.1 RADIOMETRIC GAIN CALIBRATION MEASUREMENTS

Whereas the operational PDS data processor routinely performs processing on gain measurements, it actually does not directly apply the results to the scene measurements that it is processing. In stead, the data are provided to the independent calibration chain, where an assessment is performed, and an updated set of auxiliary files (MIP_CG1_AX, MIP_CO1_AX) is produced containing the gain parameters actually to be used by the operational data processor for the calibration of scene measurements.

6.2.2 LINE-OF-SIGHT CALIBRATION MEASUREMENTS

LOS Calibration Results are routinely processed by the independent calibration facility according to the algorithms specified in [AD8]. The resulting estimates of pointing bias and harmonic pointing errors are provided in an auxiliary file (MIP_CL1_AX) to the ground segment to improve the altitude registration of scene measurements. The pointing information is also used to adjust the commanded pointing of subsequent LOS calibration measurements, and if large deviations are found, also the commanded pointing of scene measurements.

6.2.3 CHARACTERISATION AND VERIFICATION

Dedicated algorithms have been implemented in the calibration facility to processes the following characterisation and verification measurements. The algorithms are described in [AD8].

code	**description**	**Calibration Processor Reference**
IF0	LOS characterisation	Chain 25
IF1	On-board Gain settings	Chain 13
IF2	Spectral Characterisation	Chain 28
IF3	Aliassing Verification	Chain 14
IF-16+IF4+IF16	Non-Linearity Verification	Current chain is being modified to implement new algorithm
IF5	Channel combination verification	Chain 04
IF6	CBB and DS SNR characterisation	Chain 29
IF7	Phase Characterisation	Chain 30
IF8	Radiometric Calibration	Chain 01
IF9	Offset tangent height determination	Chain 03
IF10	$NESR_0$ verification	Chain 32
IF11	Absence of high-resolution features verification	Chain 15

Instantaneous Field-of-View Characterisation (IF14) is currently performed by interactive inspection of the dedicated observations. The methodology is described in [AD 7]. In short, the dedicated observations are inspected to determine the temporal behaviour of the detector signal due to entry and exit of the IR target into the field of view. The high temporal resolution achieved during this interferometric measurement allows to accurately determine the IFOV edges and the points of deflection of the curve of IFOV sensitivity as a function of angle.

7 CALIBRATION DATA ACQUISITION PLANNING

7.1 Overview

This chapter describes the scheduling of calibration measurements, based on the calibration requirements and the current performance of the instruments and data product quality. Changes in performance will require re-visiting of the schedules below. Adequacy of the currently implemented frequency will be reviewed at meetings of the MIPAS Quality Working Group.

7.2 Routine Calibrations

The baseline for offset calibration is one set of measurements per 5 scan sequences.

Radiometric Gain measurements will be performed once per 14 orbits in 2003 to allow careful analysis of the behaviour of the contamination on the cooled elements of the instrument. In case outgassing has led to greater stability, a reduction in frequency will be considered in order to reduce the wear on the interferometer. Starting time of the measurements is 5500 seconds after the ascending node crossing time.

Line-of-Sight calibrations will be performed once per week in 2003, in order to allow an assessment of variations over one year, and derive a new measurement frequency for the long-term. The calibration is performed once per week, and consists of a prime and a backup sequence, each consisting of two orbits. The prime sequence is scheduled each Saturday, the backup sequence activated on Sunday, but only if the prime sequence fails.

Although not a calibration mode, the nominal scan pattern is briefly interrupted once per orbit by a short SEM activity added to allow advance calculation of the latitude dependence of the nominal scan pattern of the entire orbit. The start time for this SEM is 527.1 seconds after ascending node crossing.

The wear-control cycle is not a calibration mode, but affects science data availability. It is performed once every 5 orbits and starts at 4000 seconds after ascending node crossing.

7.3 Dedicated calibration measurements

The schedule of dedicated calibration measurements is defined in detail in the Phase E data acquisition plan, but the baseline is as follows:

code	description	Frequency

IF0	LOS characterisation	1/week + 1 backup
IF1	On-board Gain settings	Verification: 1/year
IF2	Spectral Characterisation	1/ 4 scans
IF3	Aliassing Verification	1/year
IF16+IF4+IF16	Non-Linearity Verification	2/year
IF5	Channel combination verification	Verification: 1/year
IF6	CBB and DS SNR characterisation	1/ year
IF7	Phase Characterisation	1/ year (TBC)
IF8	Radiometric Calibration	1/day
IF9	Offset tangent height determination	4/year
IF10	$NESR_0$ verification	2/year
IF11	Absence of high-resolution features verification	4/year
IF14	IFOV Characterisation	1/year
IF16	Raw mode observations	6/year
Decontamination	Passive decontamination	2/year prior to IF16+IF4+IF16