APPENDIX B

Scanning Imaging Absorption Spectrometer for Atmospheric ChartographY

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ABSTRACT

The SCanning Imaging Absorption SpectroMeter for Atmospheric CHartographY is an instrument which measures backscattered, reflected and transmitted light from the earth's atmosphere and surface. SCIAMACHY has eight spectral channels which observe simultaneously the spectral region between 240 and 1700 nm and selected windows between 1940 and 2400 nm. Each spectral channel contains a grating and linear diode array detector. SCIAMACHY observes the atmosphere in nadir, limb and solar and lunar occultation viewing geometries.

1. INTRODUCTION

Over the past 20 years the recognition that the atmosphere may be adversely affected by human activity has become a source of public concern. In particular, attention has been focussed on:

- The potential atmospheric warming which results from increasing concentrations of greenhouse gases (e.g., CO_2, CH_4, N_2O and O_3).
- The catalytic destruction of stratospheric O_3 caused by the tropospheric release of chlorofluorocarbon compounds, emphasised by the recent appearance of the antarctic ozone hole.
- Increased tropospheric photochemical oxidant formation, which is transported to rural areas and causes damage to agriculture.
- Smog and pollution episodes in industrialised countries.
- Increased acid deposition, which results in damage to soils, forests and lakes.
- Deforestation of the tropical rain forests and biomass burning in the tropics and subtropical regions.

In order to understand and assess the importance of changes in atmospheric composition arising from anthropogenic activity and natural phenomena, a detailed knowledge of the global spatial distribution and temporal variability of atmospheric constituents is required.

Remote sensing of the atmosphere from satellite platforms, when and where possible, is the most suitable method for deriving knowledge about the global atmospheric composition. The SCanning Imaging Absorption SpectroMeter for Atmospheric CHartographY, SCIAMACHY, whose primary goal is the measurement of the abundance of atmospheric constituents[1] was first proposed in 1988 in response to the Announcement of Opportunity for the first European Space Agency (ESA) polar platform mission (POEM-1). In 1989 SCIAMACHY was selected as part of the model payloads to fly on board two future satellites:

1. The ESA Polar Platform POEM-1, planned for launch in 1997.
2. The Atmospheric and Ocean Satellite (ATMOS), planned for launch in 1995.

The Phase A and B1 studies of SCIAMACHY, which began in the summer of 1989, have been funded by the Federal Republic of Germany and by the Netherlands. Phase B1 was completed in spring 1991.

2. SCIAMACHY SCIENTIFIC OBJECTIVES

SCIAMACHY is a passive remote sensing instrument operating between 240 and 2400 nm. It determines the atmospheric amounts of atmospheric constituents primarily from their "fingerprint" absorptions. The primary aim of SCIAMACHY is to measure total column, stratospheric, and tropospheric amounts of a variety of important atmospheric gases. In addition, SCIAMACHY will provide new information about the global distributions of atmospheric aerosol, clouds and cloud top heights.

The molecular species selected for measurement by SCIAMACHY are listed in Tables 1a and 1b. Aerosols, clouds, polar stratospheric clouds (PSCs) and Polar Mesospheric Clouds (PMCs) will also be measured by SCIAMACHY.

Table 1a

SCIAMACHY TARGET MOLECULES

Molecule	Wavelength (nm)	Comments
Primary Targets:		
O_3 (Hartley Band)	240-300	
O_3 (Huggins Bands)	300-350	
O_3 (Chappuis Bands)	400-700	
NO	240-300	Above 40 km
NO_2	300-700	
NO_3	600-700	Lunar occultation only
H_2O	500-2400	
O_2	500-762	Penetration depth
O_4	380-1400	and cloud top height
$O_2(1\Delta)$	1000-1400	Strat/mes emission
BrO	300-390	
CO	2300-2400	
CO_2	1980-2020	
CH_4	2250-2400	
N_2O	2250-2350	
HF	2300-2400	Occultation only

Table 1b

SCIAMACHY TARGET MOLECULES

Molecule	Wavelength (nm)	Comments
Secondary Targets:		
(not observable under conditions of a clean background or unperturbed atmosphere)		
OClO	300-440	Ozone hole
ClO	260-320	Ozone hole
HCHO	300-350	Pollution episodes
SO_2	300-320	Volcanoes
NO_3	600-700	Twilight measurements

3. OPTICAL DESIGN

The SCIAMACHY instrument is being constructed by an industrial consortium comprised of Dornier GmBH (Project Manager, Friedrichshafen) and OHB-Systems GMBH (Bremen) in Germany and TNO-TPD (Delft) and SRON (Utrecht) in the Netherlands. TNO-TPD have been responsible for the optical design engineering. The instrument consists of three main parts: a scanning mirror system, a telescope and a spectrograph. The following functional specifications define the optical design:

- Field of view (FOV) 0.023° x 2.3°.
- Spectral range: the spectrograph has eight optical channels covering the wavelength region from 240 nm to 2400 nm. The channels are described in Table 2.

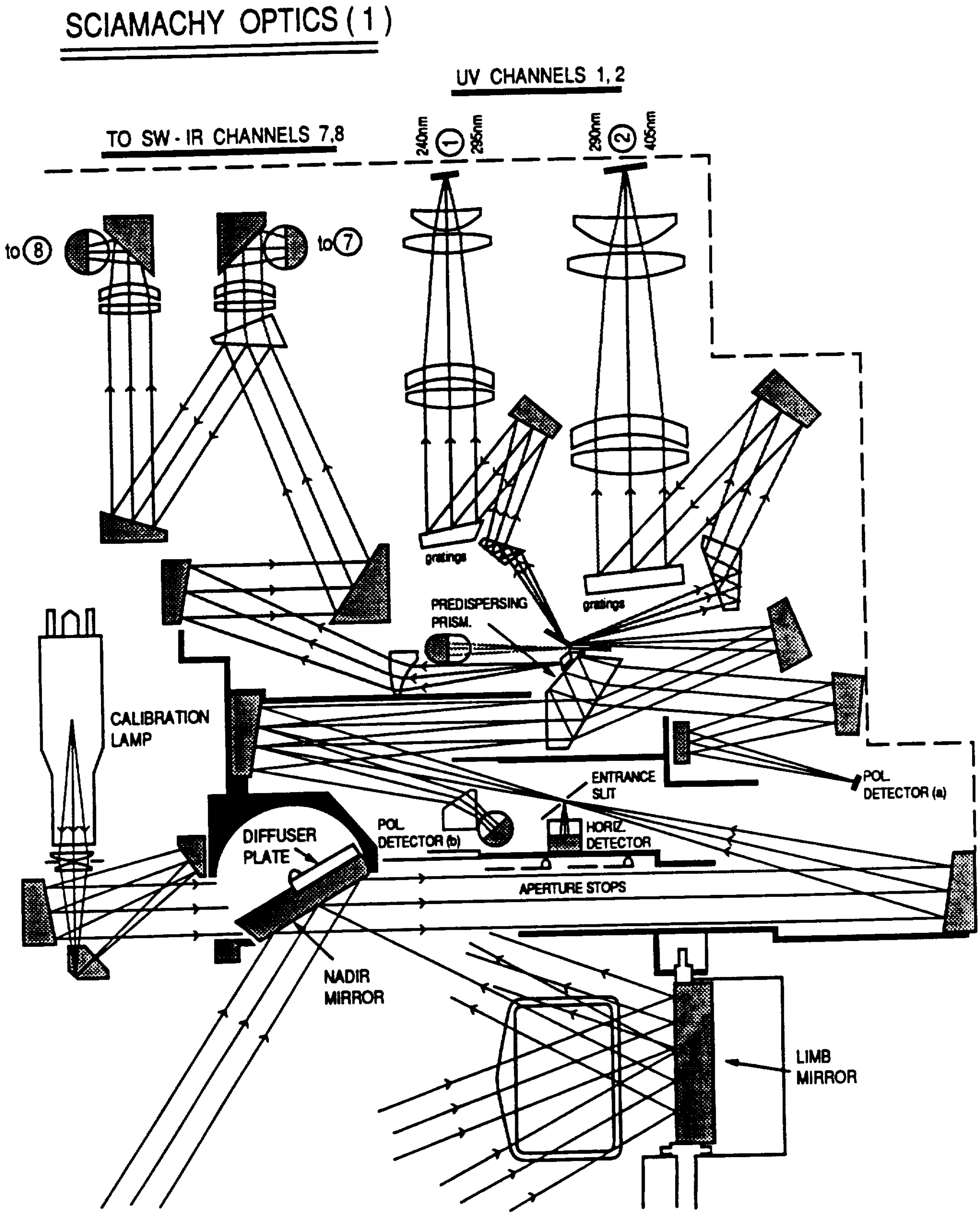
Table 2

SCIAMACHY CHANNELS

Channel No.	Wavelength Range (nm)	Detector Pixel Resolution (nm)	Spectral Resolution (nm)
1	240-295	0.11	0.22
2	290-405	0.11	0.22
3	400-605	0.2	0.4
4	590-810	0.22	0.44
5	790-1055	0.26	0.52
6	1000-1700	0.69	1.4
7	1940-2040	0.1	0.2
8	2265-2280	0.11	0.22

The main difficulty concerning the optical design of SCIAMACHY arises from the requirement to observe simultaneously a wide spectral range at moderately high resolution. This requires the separation of the light into different channels and the use of grating and echelle dispersive elements. The optical layout of SCIAMACHY is shown in Figures 1, 2 and 3.

FIGURE 1 The SCIAMACHY SPECTROGRAPH (1)



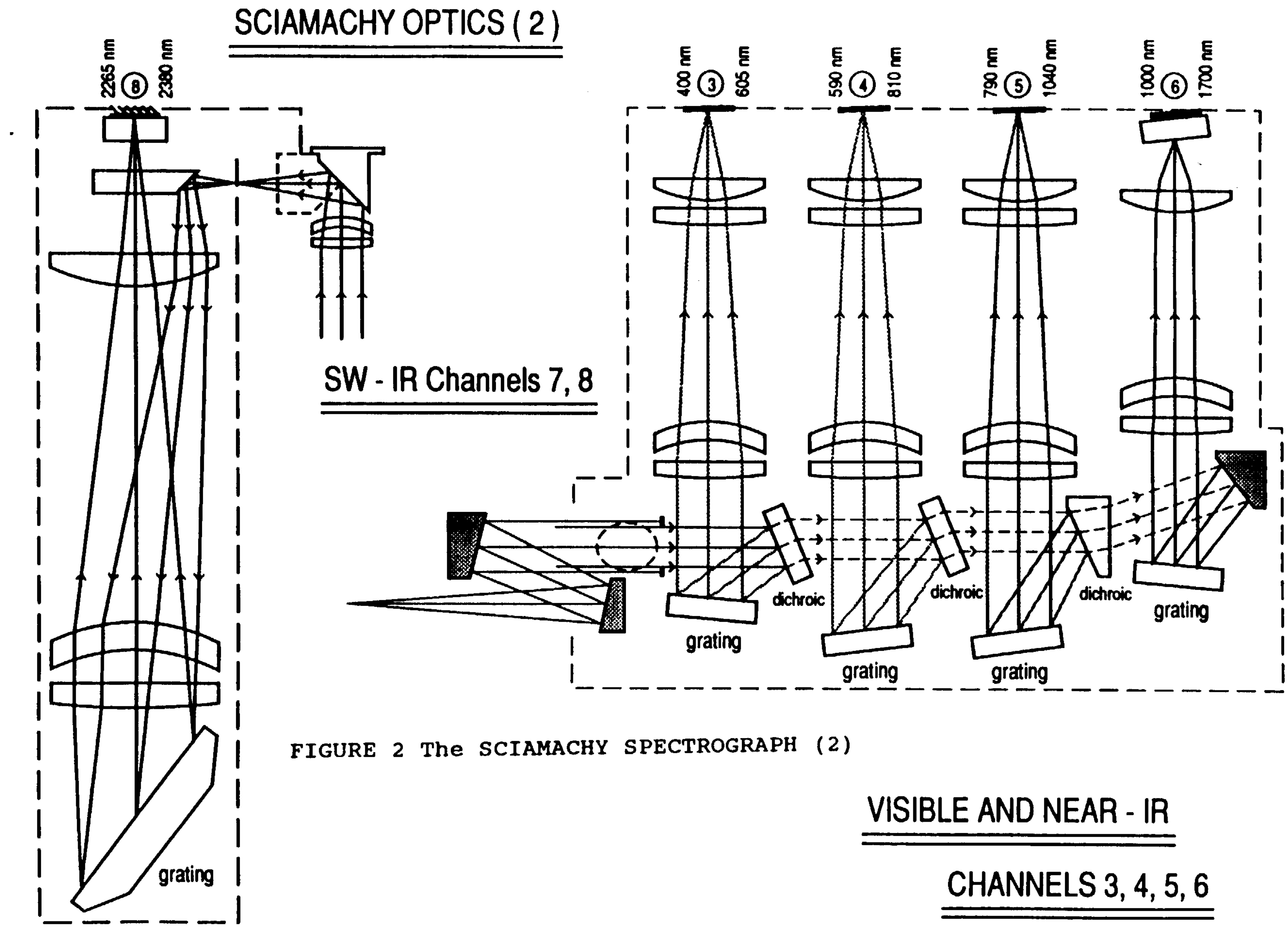
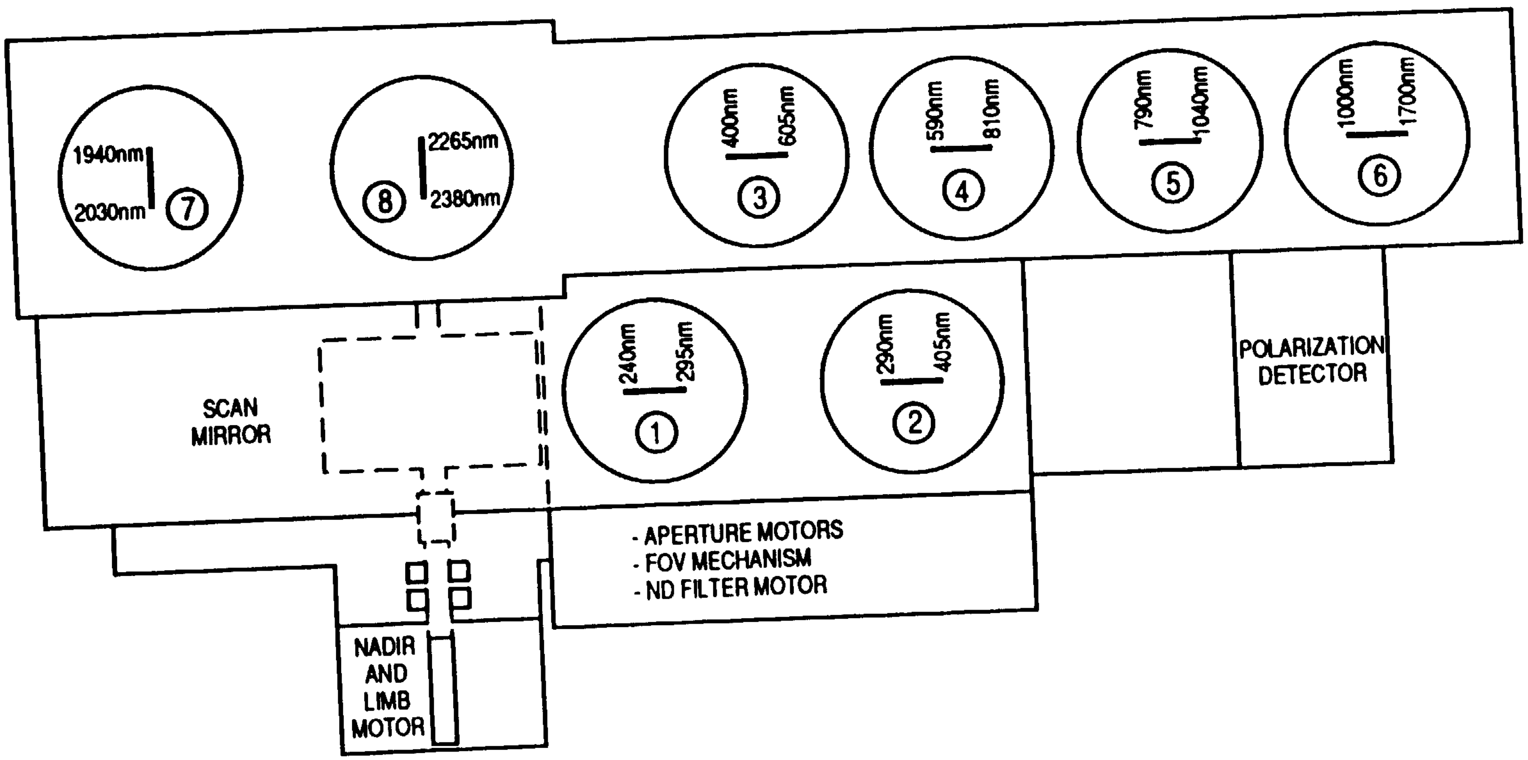


FIGURE 2 The SCIAMACHY SPECTROGRAPH (2)

FIGURE 3.The SCIAMACHY SPECTROGRAPH (3)

SCIAMACHY TOPVIEW



Transmitted, backscattered or reflected light from the atmosphere may enter the telescope via

- the nadir scanning mirror,
- the diffuser plate,
- a combination of the limb and nadir mirrors.

The off-axis parabolic telescope images the FOV onto the spectrograph entrance slit, whose front surface reflects some of the light onto a horizon sensor. Thereafter the light is collimated and sent to a predispersing prism. This prism has several functions:

1. It separates the light into UV (240-400 nm), visible and near infrared (VIS-NIR) (400-1700 nm), and short wave infrared (SWIR) (1.7-2.4 μm) components;
2. it produces additional plane polarized and unpolarized light beams: The reflections from the front face and the second face (i.e. internal) of the prism. These beams are sent to two sets of detectors. In this manner the polarization of the incoming light is measured.

After predispersion, the radiation is focussed onto a plane, where the UV and SWIR light beams are separated by two prisms from the visible and NIR light. This optical configuration minimises any scattered light entering either the UV or SWIR channels.

The UV, VIS-NIR and SWIR light is then sent via mirrors dichroics and prisms to channels 1 to 8. Each channel is comprised of a grating, lens and detector.

The detectors used in the SCIAMACHY spectral channels are linear diode arrays. In the spectral region 240 to 1000 nm Si diode arrays are used, each detector pixel having the dimension 25×2500 μm^2. In the 1000 to 2400 nm region diode array detectors made of graded InGaAs will be specially produced for SCIAMACHY. To reduce dark current these detectors will have the dimension 25×500 μm^2, but the same image of the earth atmosphere as that on the Si pixels will be mapped by use of an appropriate cylindrical lens.

The spectrometer can observe atmospheric absorptions either in NADIR, LIMB or SOLAR/LUNAR OCCULTATION by using two scanning mirrors.

4. OBSERVATIONAL MODES

There are two data collection modes and one calibration mode in SCIAMACHY:

1. Alternate NADIR and LIMB scanning of the atmosphere;
2. SOLAR/LUNAR (FULL MOON) OCCULTATION;
3. CALIBRATION MODE.

In sun synchronous orbits, occultation measurements are limited to latitude regions between 60° and 80° in both hemispheres. Consequently, the majority of measurements will be made using the limb/nadir scanning mode.

The spatial resolution of SCIAMACHY is as follows:

- Limb and solar/lunar occultation vertical resolution $\leq$3 km;

- Nadir scanning horizontal resolution is typically 32×75 km^2.

For the polar orbits of POEM-1 and ATMOS, it takes approximately 3 days for SCIAMACHY to obtain global coverage.

5. WAVELENGTH CALIBRATION

The wavelength response of the SCIAMACHY spectrograph will be calibrated before and during flight by using

1. standard lamp system (hollow cathode Pt/Ne or possibly low pressure Hg);
2. the solar Fraunhofer structure.

6. RADIOMETRIC CALIBRATION

SCIAMACHY will be calibrated radiometrically before flight and during flight. Prior to flight an "end to end" calibration will be made using several standard lamps. During flight several strategies will be used to monitor the radiometric performance of the instrument:

1. Direct observation of the sun and moon;
2. the use of a diffuser plate.

The performance of the individual detectors will be monitored by the use of a white light source in front of the scanning mirror and LEDs located in each channel. In addition the fixed pattern and dark current will be determined by observations of dark space.

7. RETRIEVAL OF CONSTITUENT AMOUNTS

SCIAMACHY DOAS Retrievals

SCIAMACHY retrieves total or stratospheric column amounts primarily by the differential optical absorption spectroscopy (DOAS) technique which requires only a relative radiometric calibration.

SCIAMACHY BUV Retrievals

For the retrieval of O_3 total column amounts and stratospheric profiles using algorithms based on those developed for the SBUV and TOMS instruments, an absolute radiometric calibration of the instrument is necessary.

Estimates of the precision for SCIAMACHY retrievals have been determined, and are given in Table 3.

Table 3

Precisions of SCIAMACHY Trace Gas Measurements

Molecule	Nadir Column Precision	Strat Profile Precision[a] Occultation	Strat Profile Precision[a] Limb Scattering	Trop Column Precision
O_3	1%	1%	10%	10%
O_2	1%	1%	10%	1%
$O_2(^1\Delta_g)$	1%	1%	10%	-
O_4	1%	1%	20%	2%
H_2O	1%	1%	10%	1%
CO	≤5%	≤7.5%	15%	≤5%
CO_2	1%	1%	10%	1%
CH_4	1%	1%	10%	1%
HCHO[b,c]	20%	-	-	20%
SO_2[b]	2%	-	-	2%
NO_2	1%	1%	10%	10%
NO_3	-	2%	-	-
N_2O	1%	1%	10%	5%
NO[d]	20%	1%	10%	-
ClO[e]	10%	-	-	-
OClO[e]	2%	-	-	-
BrO	10%	25%	50%	-

[a]These are precisions for recovering stratospheric concentration profiles, including all effects due to spacecraft pointing and jitter, weighting functions for absorption and, for the limb scattering geometry, weighting functions for the scattering source.

[b]Polluted tropospheric conditions.

[c]Biogenic emissions and Biomass burning.

[d]Estimated knowledge of column above 40 km.

[e]Ozone hole conditions.

8. REFERENCES

1. J. P. Burrows, K. V. Chance, P. J. Crutzen, H. van Dop, J. C. Geary, T. J. Johnson, G. W. Harris, I. S. A. Isaksen, G. K. Moortgat, C. Muller, D. Perner, U. Platt, J.-P. Pommereau, H. Rodhe, E. Roeckner, W. Schneider, P. Simon, H. Sundqvist, and J. Vercheval, "SCIAMACHY - A European Proposal for Atmospheric Remote Sensing from the ESA Polar Platform", published by Max-Planck-Institut für Chemie, D6500 Mainz F.R.G, July 1988.