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The Global Ozone Monitoring by Occultation of Stars (GOMOS) Instrument on ENVISAT: Requirements, Design and Development Status

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ABSTRACT - GOMOS is a medium resolution spectrometer designed to measure the concentrations of, and monitor the trends in, stratospheric ozone with very high accuracy and to observe other atmospheric trace gases. Using the star occultation technique, GOMOS combines the features of self-calibration, high vertical resolution and good global coverage. GOMOS can measure ozone profiles from 15 km to 90 km. Accessible altitude ranges, accuracies and global coverage are optimum on the night side. The main mission, instrument and the equipment requirements and their implications on the design and technology choices are presented. The GOMOS design has been completed and validated, the equipment level qualifications have been completed, the Instrument engineering model is currently undergoing qualification and functional testing and the integration and testing of the flight model instrument is already in an advanced state. All tests performed so far confirm that the GOMOS instrument meets and even exceeds the requirements.

1 - THE GOMOS MISSION OBJECTIVES

The mission objective of GOMOS is to measure vertical profiles of, and monitor the long-term trends in, ozone and other atmospheric trace gases with very high accuracy. The instrument will operate on both the night and the day side of the orbit, thus being able to monitor diurnal variations, and will offer global coverage. GOMOS will perform measurements in the altitude range of 15 km to 90 km. Its altitude sampling interval will be smaller than 1.7 km. GOMOS will perform on the average more than 600 measurements per day over its 4-year lifetime. Figures 1 and 2 show the gases which will be measured by GOMOS versus the altitude range as well as the spectral bands which will be used for their retrieval.

2 - THE GOMOS MEASUREMENT PRINCIPLE

The measurement principle of the GOMOS instrument is shown in Figure 3. The instrument line of sight can be successively oriented towards preselected stars and maintained whilst the star is setting behind the Earth's atmosphere observed on the horizon. During the star occultation, the ultraviolet, visible and near-infrared spectra of the star are continuously recorded.

As the star sets through the atmosphere, its spectrum becomes more and more attenuated by the absorption of the various gases in the atmosphere, each of which is characterized by a known, well-defined spectral signature. Back on the ground, these attenuated spectra recorded by GOMOS will be compared with the unattenuated stellar spectrum measured a few tens of seconds earlier, outside the atmosphere, so allowing the absorption spectra to be derived very accurately.

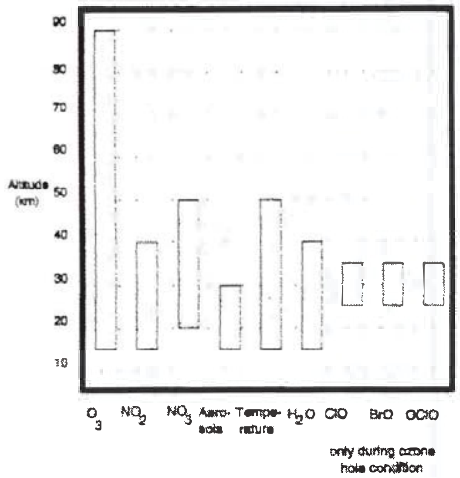

Figure 1: Measured gases as a function of altitude

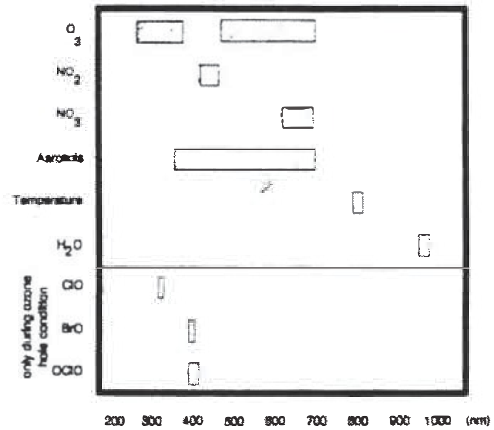

Figure 2: Relation between measured gases and wavelength range

This radiometrically self-calibrating method is protected from sensitivity drifts and is thus capable of fulfilling the challenging requirement of reliably detecting very small trends in Ozone (and other gas) profiles.

During day-side observations, the solar radiation scattered by the atmosphere is superimposed on the star signal as the line of sight starts crossing the atmosphere. In order to retrieve the star signal transmitted through the atmosphere without the background component, the (vertically imaging) spectrometers are recording the background spectrum just above and below the star too. These spectra are then used on ground for background removal.

GOMOS uses, as SAGE, the occultation measurement method, which compared to other instruments offers the advantage of high measurement accuracy and of very good altitude profiling. However, instead of using the sun as occulting source, GOMOS uses stars for performing the occultation measurements. There are more than 300 stars which are bright enough for GOMOS to observe them as they are setting through the atmosphere. Figure 4 shows a typical example of the northern hemisphere coverage of the star occultations available over one day. Over one day/one month there are typically 1600/48000 occultations to be chosen from. Selection criteria like coverage of specific latitudes/longitudes, altitude ranges, etc. can be applied, while still maintaining a good global coverage.

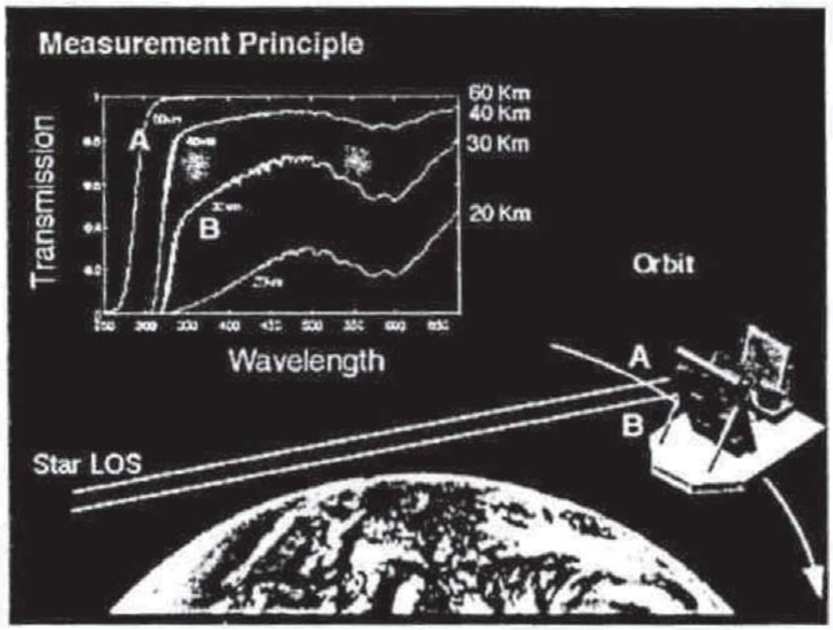

Figure 3: GOMOS measurement principle

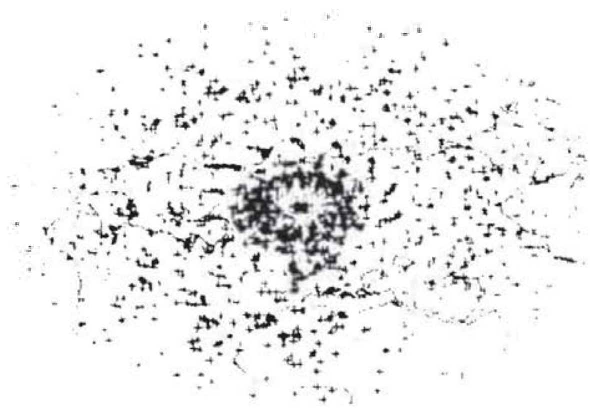

Figure 4: Typical example of northern hemisphere coverage of star occultations over one day

3 - INSTRUMENT REQUIREMENTS AND DESIGN

3.1 - The GOMOS instrument requirements and design drivers

GOMOS is a medium resolution spectrometer covering the wavelength range from 250 nm to 952 nm. The high sensitivity requirement down to 250 nm has been a significant design driver leading to an all reflective optical system design for the UVVIS part of the spectrum and to functional pupil separation between the UVVIS and the NIR spectral regions (thus no dichroic separation of UV). Due to the requirement of operating on very faint stars (down to magnitude 4 to 5) the sensitivity requirement to the instrument is very high. Consequently, a large telescope (30 cm x 20 cm aperture) is used to collect sufficient signal, and detectors with high quantum efficiency and very low noise have been developed to achieve the required signal to noise ratios.

In addition, in order to use the entire star signal, a slitless spectrometer design has been chosen. The price which had to be paid for this "light efficient" design is that a highly performant pointing system had to be used to keep the star image fixed at the input of the spectrometers in order not to degrade the spectral resolution and the spectral stability.

Achieving a high signal-to-noise ratio, when observing the very weak star signal embedded in strong surrounding atmospheric background, and at the same time stabilizing the star image in spite of the satellite disturbances have been the major engineering challenges for the GOMOS design. The main instrument requirements and the resulting design drivers are summarized in Table 1.

3.2 - The overall instrument design

The block diagram of the GOMOS instrument is shown in Figure 5. It is based on a 30 cm x 20 cm aperture telescope, whose pupil is shared by the UVVIS and NIR spectrometers and by two redundant star trackers. This function is fulfilled by the optical beam dispatcher. A two-stage steering front mechanism (SFM) moving a 32 cm x 40 cm flat mirror is used to point the line of sight towards the selected star and to track it with very high accuracy as it sets through the atmosphere. The telescope, the optics, all sensors and their associated front-end electronics are mounted on a thermally controlled optical bench. This telescope and optical bench assembly (TOBA) and the SFM are mounted via a GOMOS interface structure (GIFS) to the spacecraft. The entire spacecraft-external GOMOS instrumentation (opto-mechanical assembly: OMA) is covered by an opto-mechanical cover responsible for protecting the instrument from light coming from a different direction than the defined angular range and for ensuring a stable, defined thermal environment. The OMA is connected to the instrument electronics consisting of the sensor detection electronics, the redundant instrument control unit and the redundant mechanism drive electronics in the payload equipment bay of the satellite via a dedicated harness.

Table 1: Summary of main instrument requirements and their relation with instrument design drivers.

Requirement description	Requirement	Design driver for:
Occulting stars characteristics	Visual magnitude range: Max. -1.6 to min. 2.4 to 4 for stars with 30000K and 3000K temperature respectively	* High sensitivity and dynamic range requirements for the star tracker * High sensitivity and dynamic range spectrometer detectors (especially in the UV) * Large telescope and high transmission optics needed to collect sufficient signal from the faint stars.
Spectral range of the spectrometer: UVVIS: NIR:	 250 - 675 nm for UV and VIS 756-773 nm and 926-952 nm	* Wide spectral range, high transmission optics. * Functional pupil separation between UVVIS and NIR * Very strict contamination control to avoid UV sensitivity degradation. * Broadband sensitive and low noise detectors with high sensitivity in the UV. * High NIR sensitivity.
Spectral sampling	0.3 nm in UVVIS 0.05 nm in NIR	* Large sensors (ca. 2500 used pixels on four sensors each 1500 pixels wide) * High dispersion, high efficiency gratings
Spectral resolution	1.2 nm in UVVIS 0.2 nm in NIR	* High imaging quality optics * Very high pointing system stability requirements
Spectral stability knowledge in dark limb	0.07 nm in UVVIS 0.016 nm in NIR	* Star tracker and pointing system
Photometer spectral windows and sampling rate	470-520 nm and 650-700 nm 1 kHz sampling rate	* Fast (1 kHz), high sensitivity detectors
Short term radiometric stability (over 150 s)	1%	* Spatially uniform detectors and very high pointing stability
Linearity	1%	* High detector and electronic chain linearity (very challenging for the extremes of the dynamic range)
Pointing stability	Better than 40 microradians peak-peak	* High speed, high accuracy closed-loop pointing system
Number of occultations per orbit	45 on average, i.e. approximately 920000 occultations during the 4-year mission.	* Challenging requirement for the star pointing mechanism in terms of long term performance and reliability.
Angular coverage	-10 deg. to +90 deg. with respect to the flight direction. Thus, large instrument angular range observability	* Large total angular travel range for the mechanism.

The main spacecraft resource requirements of the GOMOS instrument are:
- Instrument mass: 175 kg.
- Instrument power consumption: 200 W.
- Data rate to satellite: 226 kbit/s

3.3 - The equipment requirements and design

3.3.1 - The Steering-Front Mechanism (SFM)

The SFM is a one mirror two axis pointing system capable of pointing the line of sight within an angular range of 100 degrees in azimuth and 6 degrees in elevation with a pointing accuracy of typically few microradians. It is based on a rectangular Beryllium mirror (size: 40 cm by 32 cm) and on a two stage - coarse and fine - pointing system. During the 4 years mission lifetime the SFM will acquire and track over 750000 stars.

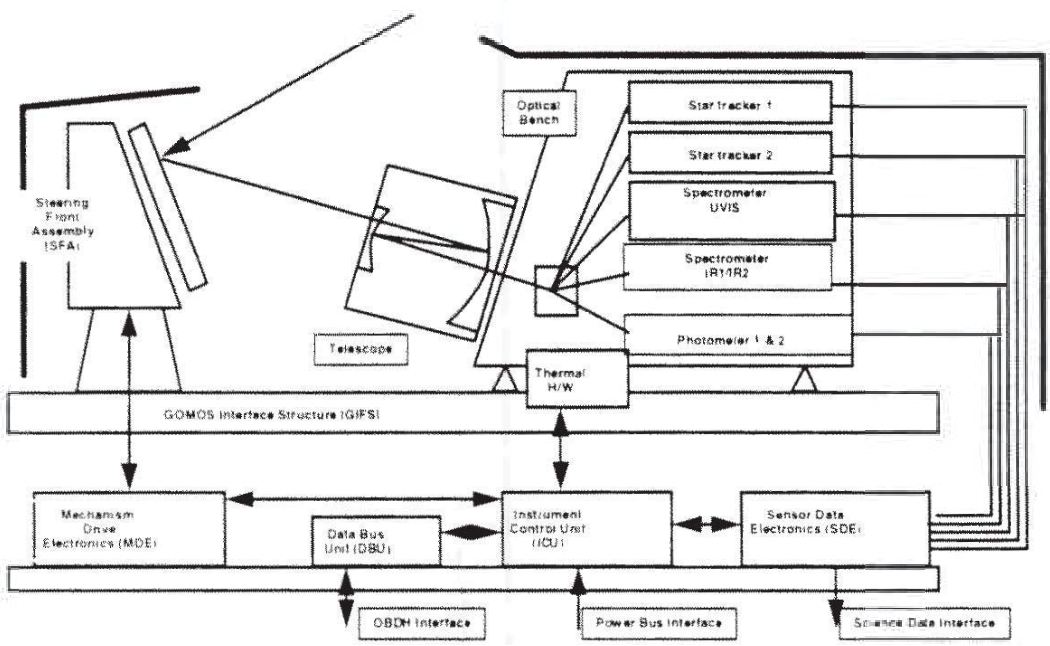

Figure 5: GOMOS instrument functional block diagram

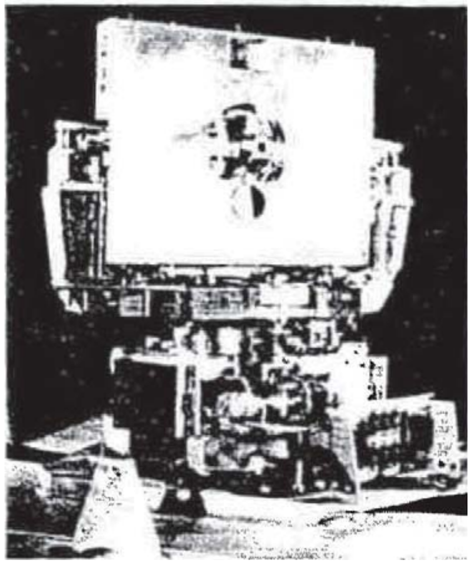

Figure 6: Steering Front Mechanism

3.3.2 - The telescope

The GOMOS telescope is a rectangular, Cassegrain telescope with a CFRP structure. It has four subpupils (one each for the UVVIS, the IR and the two star tracker channels as described in Section 5.2). The star tracker field of view is +/-0.3 degrees while the field of view of the spectrometer channels is +/- 0.015 degrees

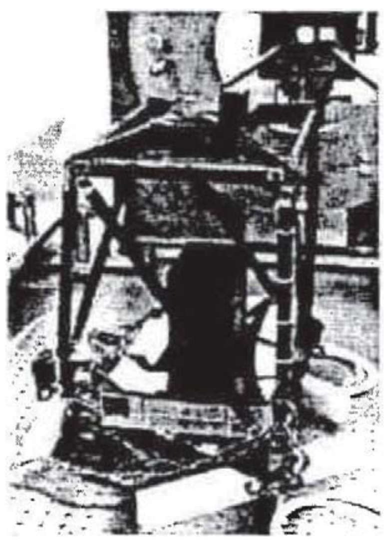

Figure 7: Telescope

3.3.3 - The UVIS spectrometer

The UVIS spectrometer provides a medium spectral resolution (0.3 nm/pixel) over a spectral band spanning 250 nm to 675 nm.

The spectrometer design and its accommodation on the optical bench have been optimized in order to maximize efficiency, mainly in the UV part of the spectrum.
The UVIS spectrometer design is based on an aberrations corrected ion-etched holographic grating as main element of the spectrometer. This enables the imaging and the spectral dispersion to be performed by one single element. The blaze wavelength is located at 305 nm, so the UV band diffraction efficiency is maximum.

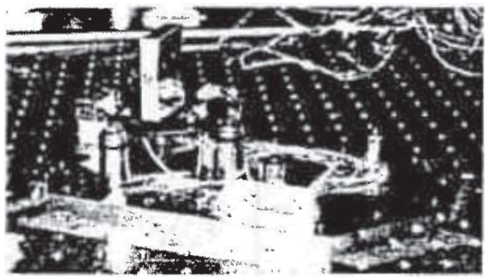

Figure 8: UVIS Optical Module

3.3.4 - The IR spectrometer chain

The IR spectrometer provides a high spectral resolution (0.05 nm/pixel) over two narrow spectral bands

- IR1 : 756 - 773 nm
- IR2 : 926 - 952 nm

The spectrometer is based on a Littrow configuration. The main design drivers concerning the IR spectrometer are the imaging quality and the transmission.

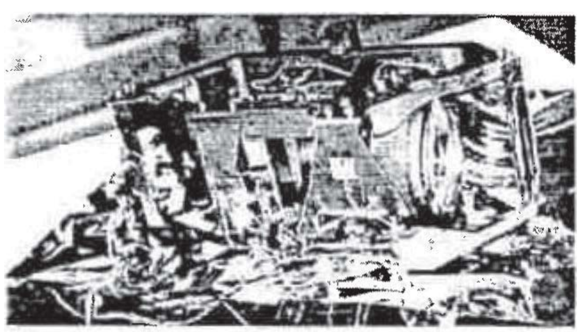

Figure 9: IR Optical Unit

3.3.5 - The Star Acquisition and Tracking Unit (SATU)

The nominal and redundant star tracker channel provides on each detector an image of the observed star The star tracker spectral band is 625-1050 nm, and it is selected by a high-pass filter located close to the detector plane. The upper limit of the SATU spectral band corresponds to the limit of sensitivity of the detector.

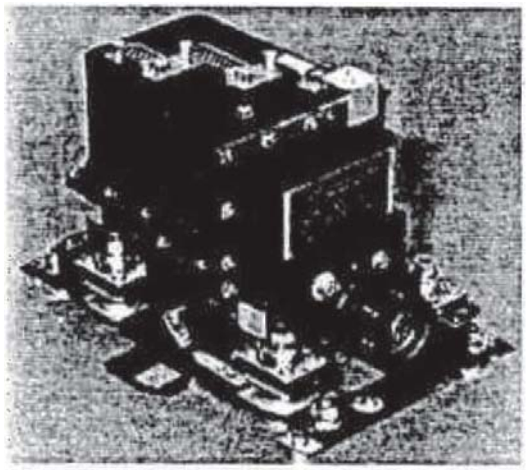

Figure 10: SATU Detection Module

3.3.5 - Spectrometer UVIS/IR detector

For the UVIS/IR spectrometer, GOMOS is using thinned backside-illuminated frame transfer CCD devices manufactured by EEV (UK). The array consists of 143 lines with 1353 pixels of 20 by 27 micrometers. Two of them are used in both DMS-A (UVIS) and DMS-B (IR) in order to meet the detection requirements. The CCD's are MPP devices ensuring very low dark current at room temperature (consequently low noise).

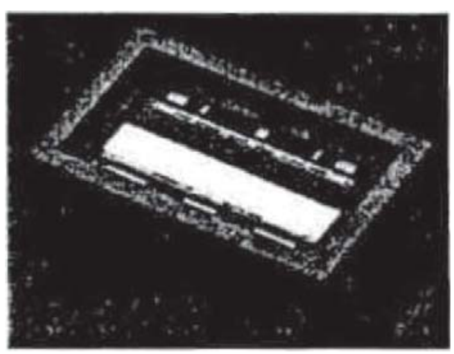

Figure 11: UVIS/IR CCD

The main CCD characteristics are :

- pixels : 20 µm x 27 µm
- image zone : 143 x 1353 pixels
  memory zone : 143 x 1353 pixels
- dark signal : < 25 pA/cm² at BOL @ 20°C.
- Image zone pixel charge capacity : $5.9x10^5$ e^-
- Register charge capacity : $1.2x10^6$ e^-
- CCD linearity : < 0.6 %

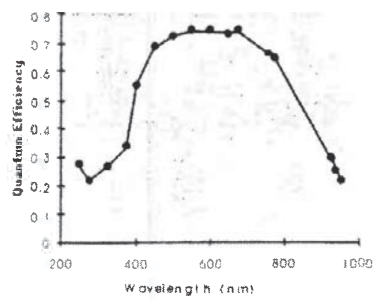

Figure 12: UVIS/IR CCD QE

Figure 13: UVIS Detection Module containing the CCD detectors and the proximity electronics

3.3.7 - Fast photometer detector

The photometer is using the high frame-rate TH31160 CCD from THOMSON. This device has been designed, realized and space-qualified within the frame of the SILEX project. Its main characteristics are :

- Frame Transfer mode
- Useful image zone : 14 x 14 pixels
- Pixel size . 23 µm x 23 µm (100% aperture)

Read-out frequency: 1000 frames/s

3.3.8 - Star Acquisition and Tracking Unit (SATU) detector.

The CCD device which is used for the SATU detection chain is TH 7863B from THOMSON. This device is a modified version of the TH 7863A designed, realized and space qualified within the frame of the SILEX project.
The main characteristics are

- Frame transfer mode
- Image area : 288 x 384 pixels
- QE :
  - 600 nm : 0.4
  - 800 nm : 0.4
  - 900 nm : 0.2

Dark current BOL <1 nA/cm².

4 - GOMOS DEVELOPMENT STATUS

The GOMOS instrument development is based on breadboard, engineering/qualification and flight models. Generally, the breadboard models have been used to verify the functionality and the key performances under ambient conditions. At instrument level they have been used to verify and to optimize the interfaces and the key functions of the detection subsystem and of the pointing and tracking subsystem.

The objective of the engineering/qualification models is to confirm the performance compliance when exposed to the simulated launch and in-orbit environment. The GOMOS EM equipment have been delivered, the instrument EM has been integrated, functional test have been completed and instrument level qualification is ongoing.

The instrument flight model integration, alignment and performance characterization is proceeding with a delivery date planed for May 1998.

7 - CONCLUSION

The GOMOS instrument to be carried by ENVISAT-1 is in an advanced state of development. The instrument design is completed and performance tests and analyses indicate a performance level compliant with the requirements. GOMOS will exploit for the first time the very accurate star-occultation measuring principle for monitoring the earth atmosphere. It will deliver very accurate ozone profiles and trend measurements. In synergy with the other ENVISAT-1 instruments. GOMOS promises to contribute significantly to environmental monitoring and to our understanding of the mechanisms governing atmospheric chemistry.

8 - ACKNOWLEDGMENT

We would like to use this opportunity to express our thanks and recognition to the following people and groups who have so far contributed significantly to the development of the GOMOS instrument:

To the GOMOS Science Advisory Group and in particular to J.L. Bertaux from Service d'Aeronomie France, G. Leppelmeier from the Finnish Meteorological Institute. Paul Simon from IASB and to C. Readings from ESA. all of whom initiated, promoted and supported very actively the GOMOS mission since its very beginning.

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