First results of GOBELIN project :
GOME Breadboard Model characterisation under ambient and vacuum conditions

I. Aben, M.R. Dobber, F. Helderman, R. Hoogeveen, P. Stammes*) and A.P.H. Goede

Space Research Organization Netherlands (SRON)
Sorbonnelaan 2,
3584 CA Utrecht,The Netherlands.
*)Royal Netherlands Meteorological Institute (KNMI) Postbus 201,
3730 AE De Bilt, The Netherlands.
i.aben sron.ruu.nl
http://www.sron.ruu.nl/general/divisions/eos/gobelin.html

Abstract

In-flight monitoring of the optical response of GOME revealed a number of instrumental features that drift or change with time. Some of these observed features are related to outgassing of the instrument in space. In particular outgassing of optical coatings, e.g. the dicroic mirror in GOME, can result in a change of the optical characteristics and thereby changing the response of the GOME instrument. Another feature is related to the etalon effect which results in a spectral modulation of the GOME spectra. This modulation varies in time due to a varying contamination layer, most likely ice, on the cooled detectors.

Through the GOBELIN project the GOME Breadboard Model has been made available to us by ESA. The GOME Breadboard Model has been fully upgraded to the GOME Flight Model and therefore offers a unique opportunity to study the above phenomena under controlled laboratory conditions. First results are presented addressing in particular the effect of outgassing on instrument optical response, including the polarisation response, and the etalon effect.

Keywords: GOME, GOME Breadboard Model, characterisation, calibration, vacuum

1. Introduction

The Global Ozone Monitoring Experiment (GOME) on board the ERS-2 satellite was launched in April 1995. GOME has been designed to measure column densities of trace gases in the Earth's atmosphere, and it is the first European satellite instrument that observes the Earth's ozone layer from space. GOME measures accurately the Earth's radiance from 240 to 790 nm in four spectral channels. The spectral resolution of the GOME channels varies from 0.2 nm in the ultra-violet to 0.3 nm in the visible range.

For in-flight calibration purposes, GOME measures the extra-terrestrial solar irradiance once a day since May 30, 1995. These daily GOME solar spectra provide a very powerful tool for monitoring GOME instrumental stability as the solar irradiance is known to be quite stable for the GOME wavelength range [*Lean et al., 1991*]. During the GOME Validation Campaign, which took place from mid 1995 until Spring 1996, the solar spectra revealed several time-dependent instrumental features [*Eisinger et al., 1996a*]. In Figure 1 a typical example is shown of the ratio of two solar spectra observed by GOME more than a year apart. Both spectra have been corrected for the Earth- Sun distance.

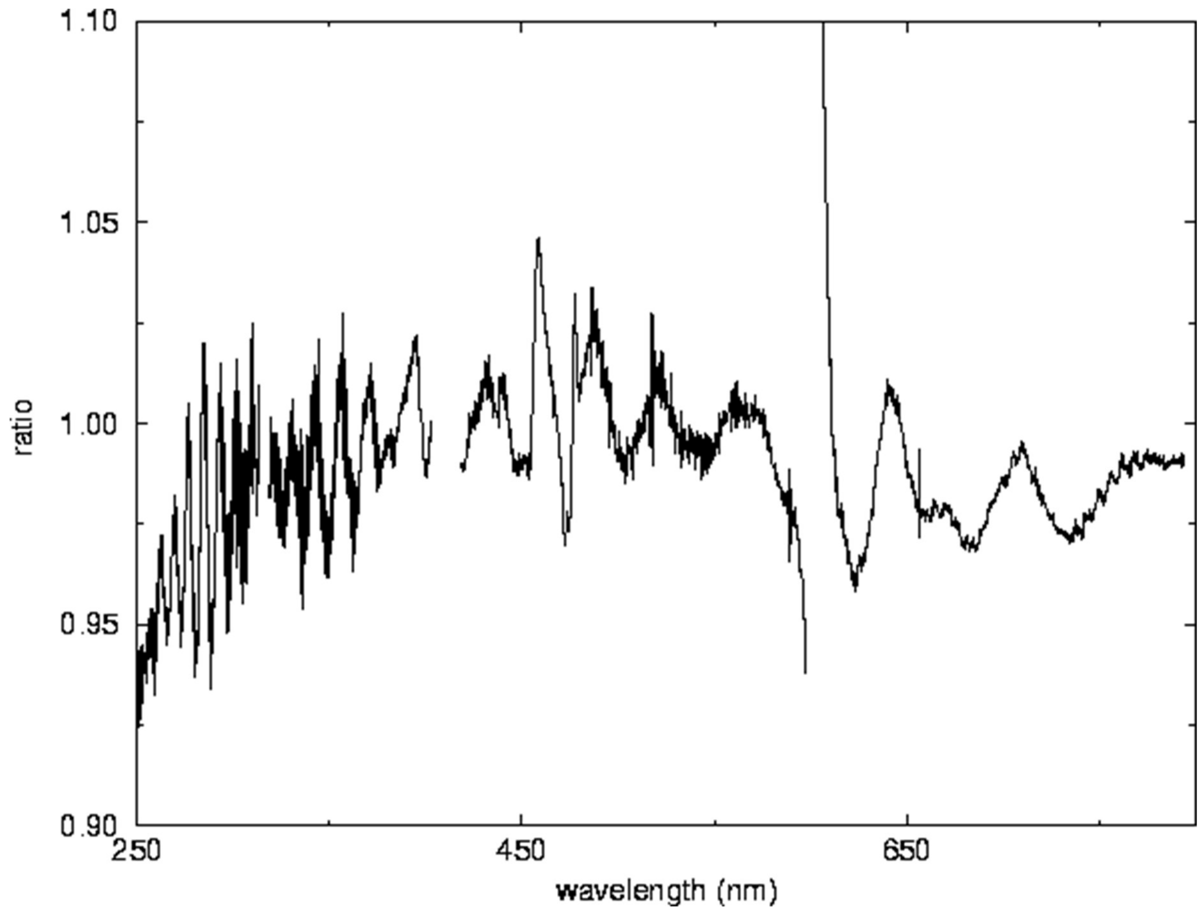

Figure 1 : ratio of two solar spectra, normalized to earth-Sun distance, obtained with GOME on September 1996, and July 1995

A clear oscillation can be seen across the full wavelength range of GOME with a period that increases with wavelength. The amplitude of this oscillation is depending on channel, where the largest amplitude is observed in channel 2. This oscillation has been attributed to the so-called etalon effect [*Eisinger et al., 1996a*, *Hoekstra et al., 1996*, *Peeters et al., 1996*]. It is caused by constructive and destructive interference of light in the passivating 3 um SiO_2 layer, which protects the Si detectors, and in addition by the ice layer which is deposited on top of it due to cooling of the detectors to 235 K. The resulting interference modulates the instrumental response with a sinusoidal function where the period is determined by the thickness of the layers. This effect cancels in the ratio of spectra when the layer is stable. It was shown that for GOME in-flight conditions the etalon stabilises within a week [*Hoekstra et al., 1996*] and the spectral modulation remains constant within 1 %. However, in particular during the first year of operation, either GOME or the GOME detector coolers were switched-off occasionally. This always resulted in a change of the spectral modulation indicating the formation of a new contamination layer.

Additional features in Figure 1 are observed in channels 3 and 4. These could be attributed to the optical characteristics of the coating of the dichroic mirror that separates the light in channel 3 and 4. Figure 2 shows the transmission curve of the dichroic mirror in air and in vacuum for unpolarised light. There is a clear shift of the transmission curve to shorter wavelength due to outgassing of the dichroic mirror coating. The most pronounced effect is observed in the overlap region between channels 3 and 4. A shift in the cut-off wavelength results in a strong change in response in this region which is clearly observed in Figure 1. Prior to launch GOME was calibrated on-ground under ambient conditions whereas GOME in-flight is operated in vacuum. A correction of the calibration keydata was therefore applied to transform the dichroic response in air to its response in vacuum in the data processing. However, this is a static correction and can therefore never correct for time dependent changes in the dichroic response observed.

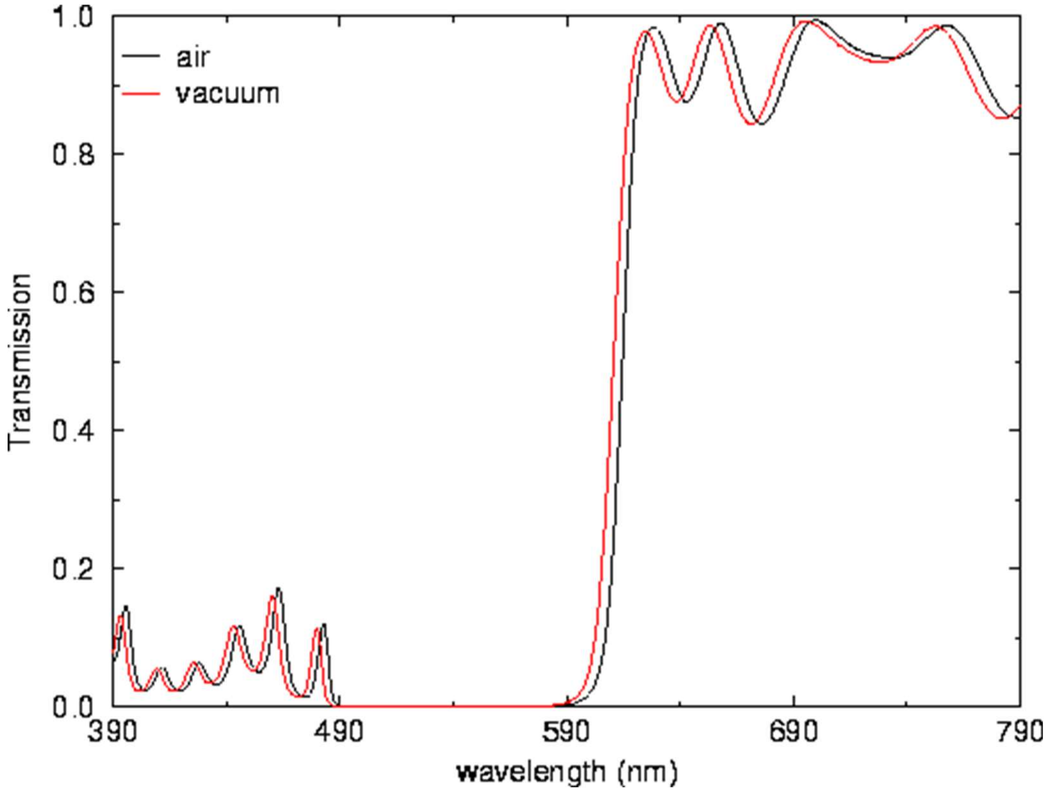

Figure 2 : Transmission of dichroic mirror measured in air and in vacuum with unpolarised light [TNO-TPD]

An additional complication arises through the polarisation dependence of the transmissivity of the dichroic mirror. The polarisation sensitivity of the instrument is characterised by the calibration keydata parameter Eta. Eta is the ratio of the sensitivity of the nadir viewing instrument for p-polarised light, which is light polarised parallel to the GOME entrance slit, to s- polarised light. As the dichroic features are strongly polarisation dependent it was anticipated that Eta is different under ambient and vacuum conditions. Again a correction was applied to the keydata to take the air - vacuum changes of Eta into account. This correction is based on transmissivity measurements of the optical response of the dichroic mirror in air and in vacuum. However, Differential Optical Absorption Spectroscopy (DOAS) analyses of total ozone showed [*Eisinger et al., 1996a*, *Eisinger et al., 1996b*] that the correction is not adequate.

To assess the absolute accuracy of the GOME solar irradiances, GOME solar spectra were compared with solar spectra obtained with other satellite instruments such as SSBUV, SOLSTICE and SOLSPEC [*Hoekstra et al., 1996*, *Peeters et al., 1996*, *Hilsenrath et al., 1996*]. The agreement between these instruments and GOME is reasonably good above 400 nm, but there is a clear wavelength dependent deviation with a characteristic parabolic shape between 240 - 400 nm with a maximum deviation of ~ 18 % at ~ 350 nm where GOME irradiance is less. These differences have been explained again by air-to-vacuum changes in GOME sensitivity. This was later qualitatively confirmed by re- analyzing the thermal vacuum test measurements [*Hoekstra et al., 1996*]. A first order in-flight correction for this effect is part of the present operational data processing procedure. The correction is based on the line intensity changes of the internal Spectral Light Source (SLS) observed pre-flight and in-flight. The remaining deviation with other instruments is thereby reduced to less than 10 % and the wavelength dependence is much less pronounced.

Through the GOBELIN (GOME Breadboard Model Experimental LINk) project the GOME Breadboard Model (BBM) has been made available to us by ESA. The GOME BBM has been fully upgraded to represent the GOME Flight Model (FM) and therefore offers a unique opportunity to study the phenomena as observed with GOME in-flight under controlled laboratory vacuum conditions. The focus of this paper is on the first experimental results addressing the effect of outgassing on instrumental response, including the polarisation response, and the etalon effect.

2. Experimental setup

A vacuum system was built which accommodates the GOME BBM. With this system a final pressure of less than 10^{-6} mbar was reached during the present measurements. The GOME BBM optical response varies with the Optical Bench Module (OBM) temperature. To achieve a stable OBM temperature in vacuum a temperature controlled system was built. All the measurements presented in this paper have been performed with the OBM at a temperature of 295.1 K +/- 0.2 K. The measurements are performed with cooled detectors (235 K) in order to obtain good signal-to- noise. The optical instrument and the detector Focal Plane Assemblies can be evacuated independently by separate vacuum systems, thus allowing to separate the effects of instrument degassing from the effects associated with the detectors, such as the etalon effect. Before starting the measurements the FPAs are evacuated and the detectors are cooled. After two days the etalon was considered stable enough to start the outgassing measurements by evacuating the GOME BBM. With this approach the outgassing effect on optical response is studied separately from the etalon effect. When outgassing was completed the etalon effect was studied. This is done by switching off the detector cooling and turning the cooling back on after the detectors have been warmed up to 291 K.

The optical response of the GOME BBM is measured by using as an optical stimulus a 6.6 A, 200 W Tungsten Halogen White Light Source (WLS) (OSRAM 64380) with a current stabilised power supply (ORIEL 68830). The output of the WLS is monitored at four different wavelengths (365, 400, 600, 800 nm) with a set of four fotodiodes each with a different interference filter. By monitoring the WLS output at different wavelengths it is possible to correct for (spectral) fluctuations in the WLS output. The preliminary results shown in this paper have not yet been corrected for these fluctuations. The WLS is situated in a separate room to minimise the influence of straylight on the measurements. A quartz transmittance diffuser is used to guarantee uniform illumination over the GOME BBM field-of-view. It is located at 30 cm from the WLS. A quartz window is mounted to the vacuum system to transmit the light to the GOME BBM. During all these measurements the GOME BBM is operated with the scan mirror in Nadir position. Spectral calibration is performed by a Pt/Cr-Ne hollow cathode discharge lamp which is identical to the internal Spectral Light Source (SLS) in GOME used for in- flight spectral calibration. The SLS is mounted on the optical rail which also accommodates the WLS, the diffuser, and the polarisers. The ultra-violet and visible sheet polarisers are used when monitoring the polarisation sensitivity of the GOME BBM.

3. Results
air - vacuum effects
unpolarised light

In Figure 3(a) and 3(b) a time series is shown for the optical response of the GOME BBM to unpolarised light while the instrument is being evacuated. The curves show the ratio of the optical response with reference to the response in air. In Figure 3(a) the effect of evacuation in the ultra-violet is shown after 2 hours and after 3 days. As was observed with GOME in- flight, there is a clear parabolic wavelength dependence in the change in ultra-violet optical response from ambient to vacuum conditions. The optical response in the ultra-violet appears to stabilise within a few hours. The oscillation observed in the ratio after 3 days is tentatively attributed to a changing etalon effect during this period.

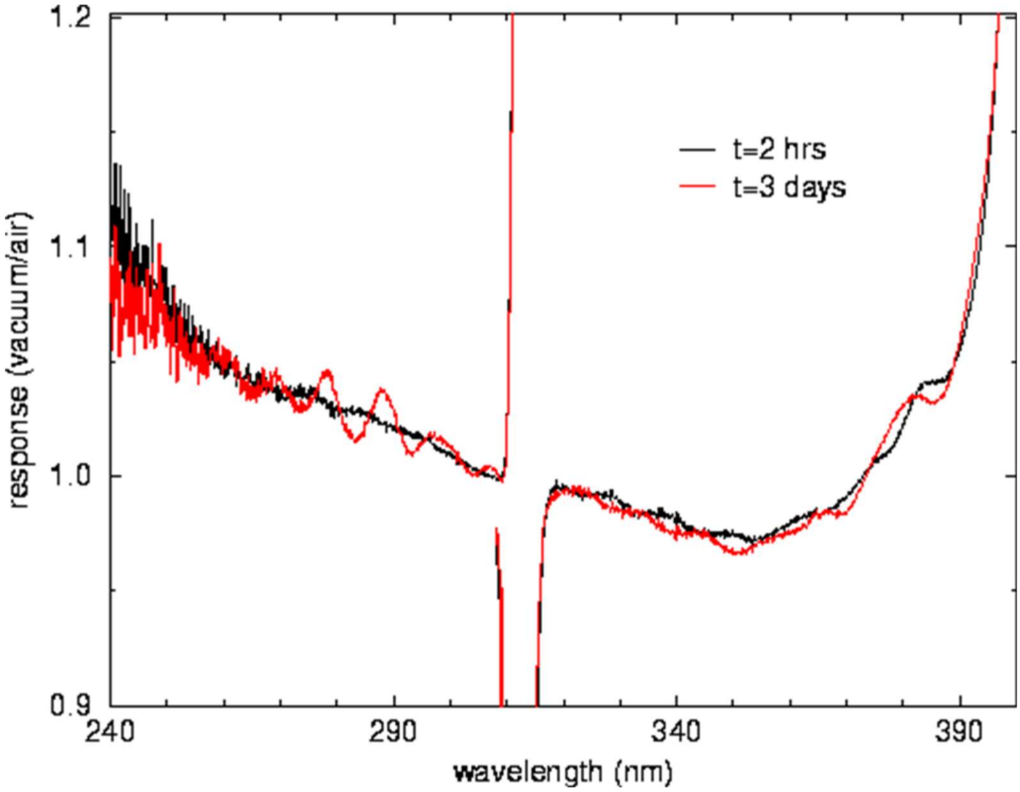

Figure 3a : GOME BBM response to ultraviolet unpolarised light with GOME BBM in vacuum, compared with response in air

In Figure 3(b) the effect of evacuating the GOME BBM in the visible is shown. When comparing Figure 2 and Figure 3(b) it appears as if the main changes observed in the visible are related to changes in the optical response of the dichroic mirror. It should be noted that fluctuations in the WLS output, although monitored, are not yet corrected for in these spectra. This might explain the change in response observed in the 500-590 nm wavelength region where no changes in transmission of the dichroic mirror were anticipated. In addition to the dichroic features a very sharp feature around 700 nm is observed in Figure 3(b) which is related to the Wood's anomaly [*Hessel et al., 1965*].

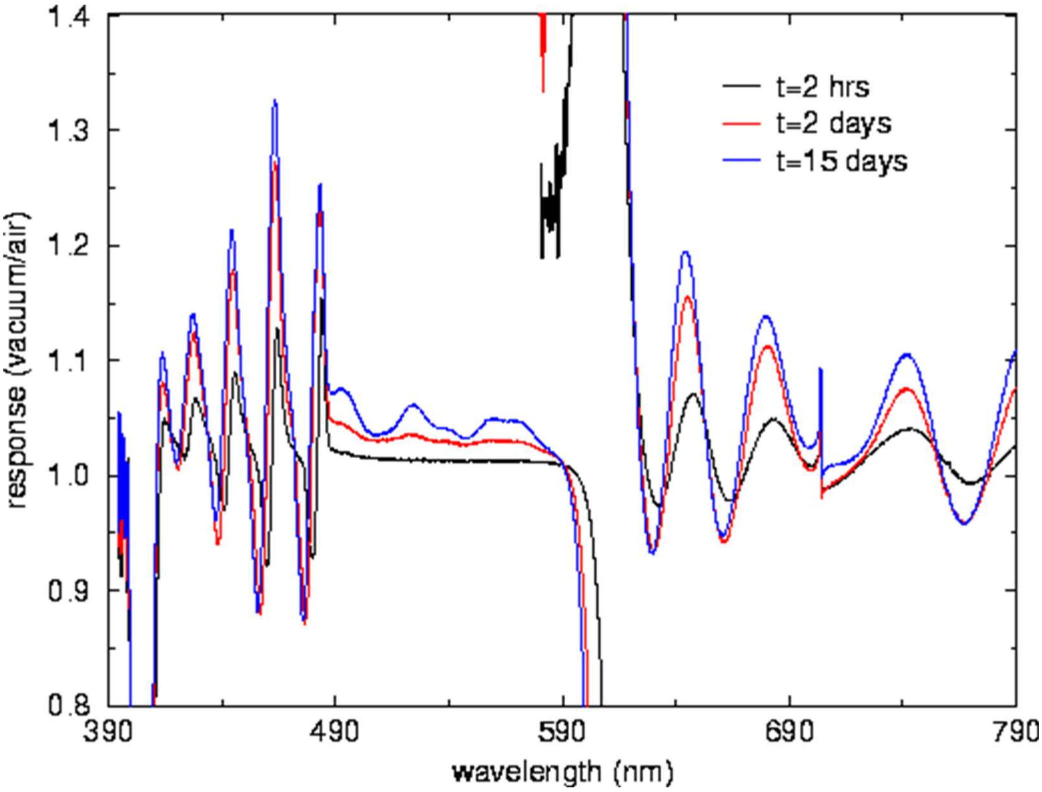

Figure 3b : GOME BBM response to unpolarised visible light with GOME BBM in vacuum, compared with response in air

polarised light

In Figure 4 Eta of the GOME BBM after 18 days in vacuum is compared with the air response. A clear shift is again evident in the overlap region between channel 3 and 4 around 600 nm, and in the wavelength region 400 - 500 nm. It turned out that there is no air-vacuum effect on Eta in the ultra-violet channels 1 and 2 (not shown in Figure 4). Eta measurements are less affected by drift in the WLS output as Eta is a ratio of two measurements obtained only a few minutes apart.

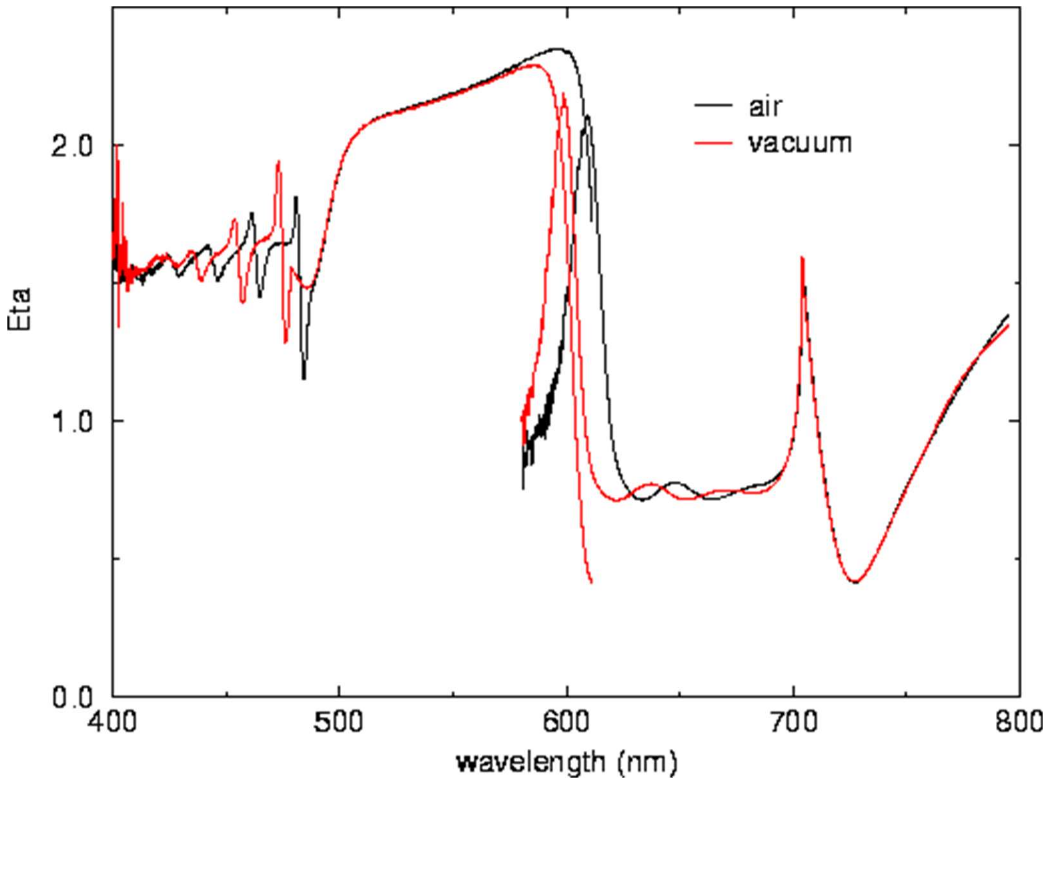

Figure 4 : GOME BBM polarisation sensitivity Eta in air and in vacuum (18 days)

etalon effect

In Figure 5 a time series is shown which illustrates the etalon effect. Outgassing phenomena are not observable on the time-scale of these measurements as the instrument has been in the vacuum for over 2 weeks. The etalon time series is obtained by warming the detectors to 291 K for a few hours after which the detector cooling is switched on again. When the detector temperature reaches 235 K the time series is started (t=0) and the optical response to unpolarised light is monitored. All the spectra are referenced to the t=0 situation. The oscillation in Figure 5 show an increase in amplitude with time which most likely resulted from a change in the contamination layer on the detectors.

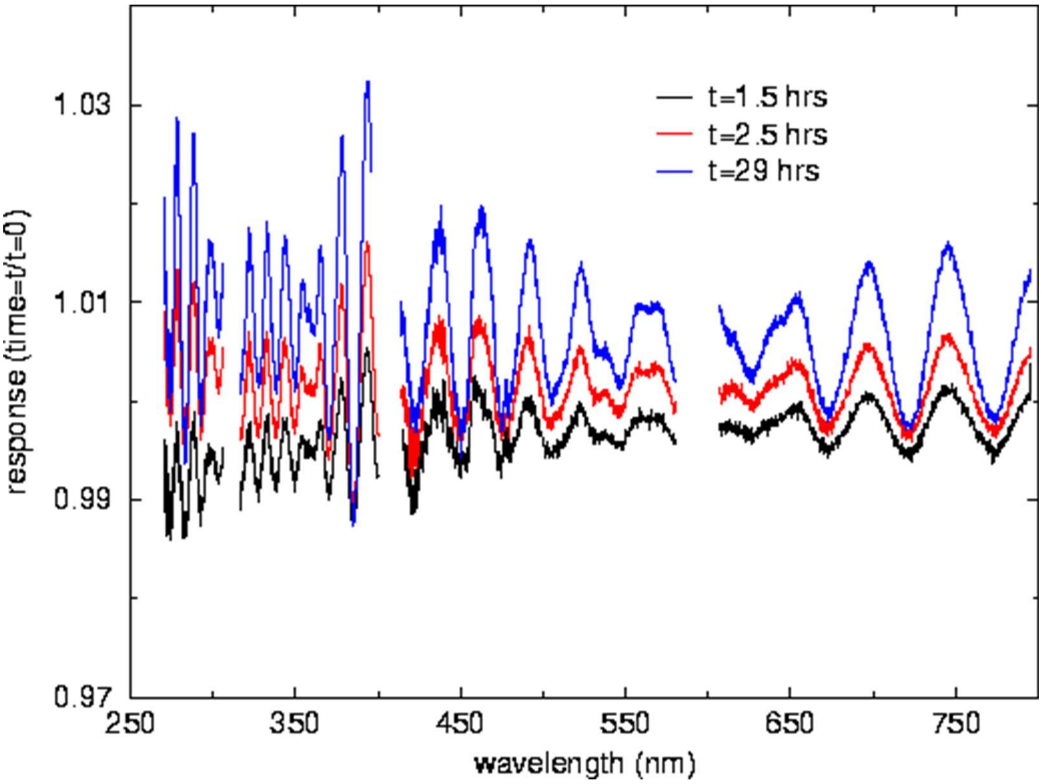

Figure 5 : Etalon time series for unpolarised light

4. Conclusions

With the GOME BBM under ambient and vacuum conditions we were able to qualitatively reproduce the time dependent phenomena observed with GOME in- flight. This includes outgassing of the dichroic mirror, the ultra-violet parabolic change, and the etalon effect. Furthermore, it was shown that air - vacuum changes only influence the polarisation sensitivity of the GOME BBM in the visible wavelength range (channels 3 and 4) and are thus most likely related to changes in the dichroic mirror. Further analysis is in progress to quantify the observed effects.

5. Acknowledgements

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