MARSCHALS

Millimetre-Wave Airborne Receivers for Spectroscopic CHaracterisation in Atmospheric Limb Sounding

1. INTRODUCTION

The MARSCHALS instrument has been designed [1] to be an airborne simulator of a future ESA space instrument (MASTER) and is the first limb-sounder to be explicitly designed and built for the purpose of Upper Troposphere (UT) composition sounding. The instrument represents the observing parameters of MASTER [2] as closely as possible and is used from an airborne platform so as to simulate the limb-sounding operation and scan profile of the space instrument.

To simulate MASTER in the Upper Troposphere & Lower Stratosphere (UTLS) MARSCHALS operates on the M55 Geophysica [3] aircraft which reaches altitudes of >20km; this offers the possibility of flying MARSCHALS simultaneously with other limb-sounding instruments such as MIPAS-STR (mid Infrared), SAFIRE-A (Far infrared) and CRISTA-NF. MARSCHALS has also been designed to be compatible with operation on a high-altitude CNES-type balloon gondola (with a correspondingly larger antenna) which, flying at altitudes of up to 40km, would permit a simulation of the mid-stratosphere measurements. MARSCHALS is shown in its flight configuration mounted within Geophysica Bay 1 in Figure 1.

Figure 1 MARSCHALS mounted in Bay 1 of the Geophysica

The principal and most innovative objective of MARSCHALS is to simulate MASTER's capability for upper tropospheric sounding of O_3, H_2O and CO in the 300, 325 and 345 GHz bands, respectively. The retrieval of data from MARSCHALS will verify the retrieval processes and performance requirements for MASTER and also confirm the technical feasibility of radiometric instruments of this type.

The unique combination of H_2O, O_3 and CO measurements in the upper troposphere is a powerful one with which to investigate stratosphere-troposphere exchange and radiative forcing of climate. Observations of HNO_3 and N_2O, which would be made in addition to those of O_3, H_2O and CO in the lower stratosphere, could offer important contributions to issues concerning aerosol chemistry and stratospheric ozone recovery.

2. Instrument Design

MARSCHALS consists of a vertically scanning antenna which views thermal emission from the atmosphere; incoming radiation is distributed into a number of discrete spectral bands, each of which is down-converted and amplified. Spectrometers measure the spectral power density across each band, and digitised outputs are available for ground processing. For reasons of cost, the design of MARSCHALS does not permit instantaneous coverage of all five MASTER bands. Instead, three bands (MASTER bands B, C and D) are time multiplexed.

The operation and configuration of MARSCHALS is shown in Figure 2 and Figure 3 respectively.

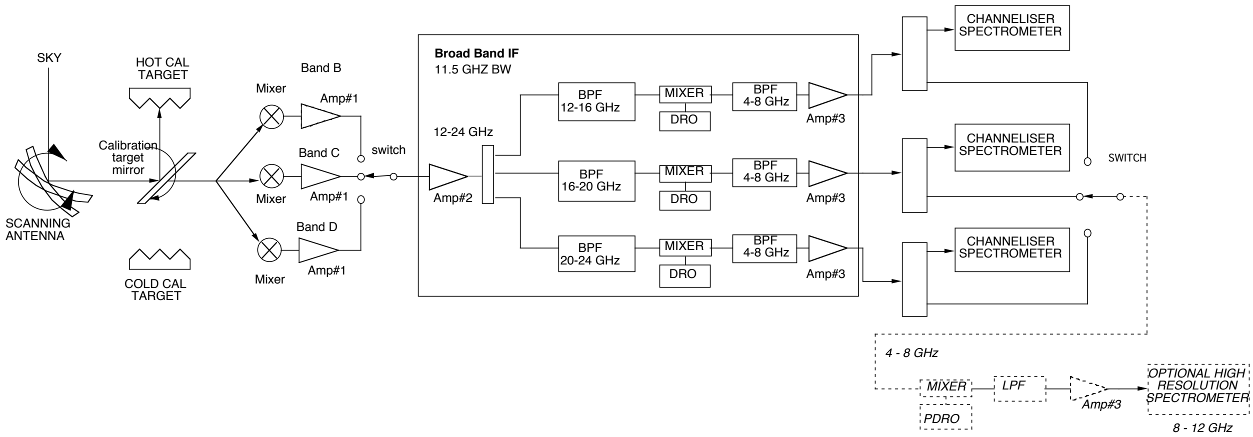


Figure 2 MARSCHALS Millimetre Wave Instrument Schematic.

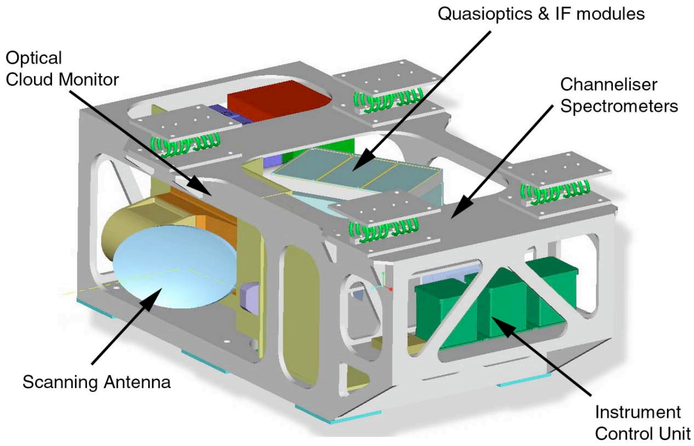


Figure 3 Configuration of MARSCHALS instrument

The performance requirements of MARSCHALS are driven by those of MASTER; the key aspects are listed in Table 1.

Table 1 MARSCHALS Design Performance Specification

Instrument Type	Total Power Single Sideband Radiometer
RF bands	Band B 294 – 305.5 GHz Band C 316.5 – 325.5 GHz Band D 342.2 – 348.8 GHz
Instantaneous bandwidth	12 GHz
Spectral Resolution	200 MHz (with provision for addition of high resolution 2MHz spectrometer with 4-12 GHz bandwidth)
NET (250ms)	<1.5K
NET (10 scans)	< 0.6K (MASTER specification)
Sideband Rejection	> 22dB (characterised to better than 30dB)
Beam Pointing	<<0.0025 deg. rms pointing knowledge during scan, bias excepted
Scan range	Tangent heights from –2km to platform altitude (21km on aircraft) in 1 km steps with +20 deg. "space view"
Mass	330kg
Dimensions	1.55 x 0.76 x 0.56m

Table 2 Geophysica aircraft performance

Cruising Altitude	Up to 21km
Cruising speed	640-720 km/hr
Payload weight	1500kg
Flight Duration	Up to 6.5 hours (5-6 hrs at max altitude)
Temperature (in instrument location)	-70°C to +40°C
Pressure (in instrument location)	40mm Hg to 760mm Hg
Humidity	Up to 100% at 35°C

3. SUBSYSTEM DESCRIPTION

Scanning antenna

Like MASTER, MARSCHALS employs a scanning antenna to view the limb at varying tangent heights. In the case of the Geophysica aircraft platform, a 235mm x 250 mm antenna is employed; a 400mm diameter antenna can also be fitted to the instrument for use on a balloon platform.

In the case of the aircraft, the antenna views the limb through an open aperture in the fuselage – there is no window. At take-off and landing, the aperture is closed by a shutter.

Figure 4 MARSCHALS Antenna seen through the open aircraft aperture

The antenna is driven by a brushless motor. Positional control is achieved by a custom-designed controller based on the Analog devices ADMC401 DSP controller, with an Inductosyn™ sensor mounted directly to the driveshaft providing positional feedback. Due to the requirement for highly accurate (0.0025° rms) knowledge of the pointing, a dedicated Inertial Measurement Unit (IMU) is mounted on the MARSCHALS instrument frame. MARSCHALS pointing is thus independent of the aircraft inertial navigation system and errors due to e.g. flexures in the fuselage or anti-vibration mounts are eliminated.

Radiometric calibration

High elevation angle views of the sky are sufficiently contaminated by spectral features, even at 35km altitude, that they are unsuitable for use in calibrating the MARSCHALS instrument. MARSCHALS therefore employs two onboard radiometric calibration targets. The first, an ambient temperature, or "HOT" load, is implemented using the Calibration Hot Load (CHL) developed by AEA Technology Space with Thomas Keating Limited under contract to ESA. This uses a conically-shaped mm-wave absorber (Figure 5).

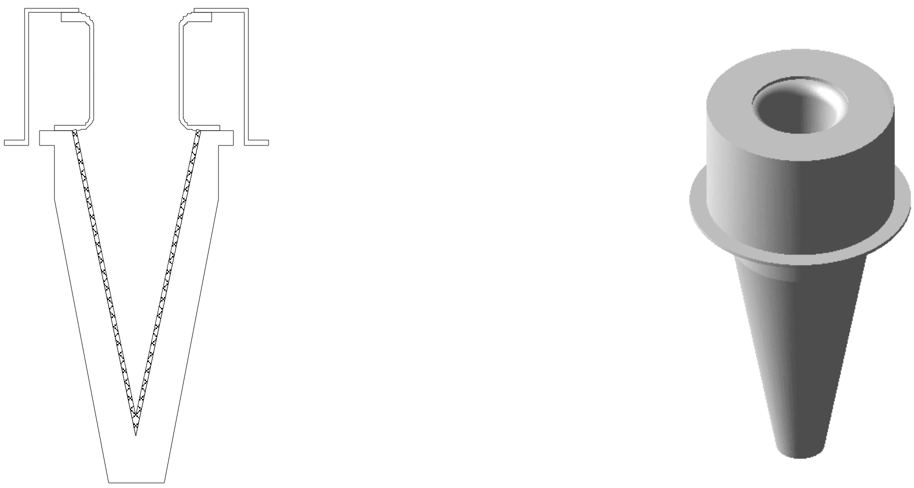


Figure 5 Calibration Hot Load

The second radiometric target, or "COLD" load, uses a pyramidally-shaped absorber cooled by liquid argon in a custom-built cryostat developed by RAL (Figure 6) with Thomas Keating Limited.

Liquid argon has been selected as the cryogen in order to avoid the possibility of liquid oxygen condensing on the cold surfaces (as might happen if liquid nitrogen were used as the cryogen).

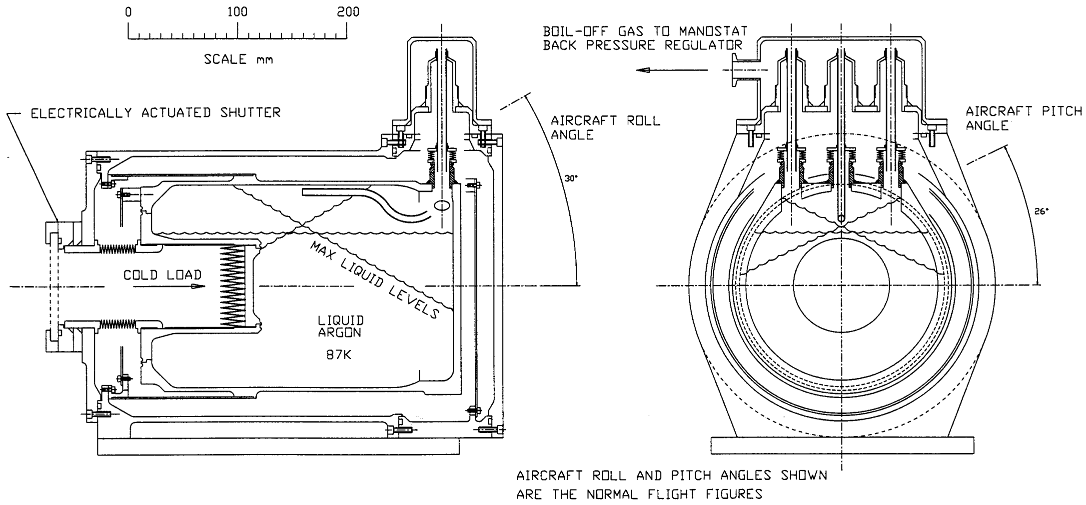


Figure 6 Calibration Cold Load

A rotating mirror is used to switch between the two calibration targets and the sky view during the limb scan (Figure 7). The switching sequence is completely programmable to allow for modifications in the light of system performance.

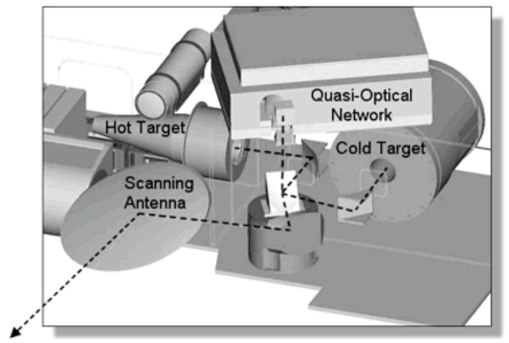


Figure 7 Calibration/Sky switching arrangement

Quasioptical network and mm-wave mixers

MARSCHALS presently incorporates three receivers for bands B, C and D although it has been designed to be capable of expansion up to a total of 5 receivers.

Incoming radiation, whether from the limb or from the radiometric calibration targets, is demultiplexed and coupled into the individual front end mixers by a Quasi Optical Network (QON) (Figure 8).

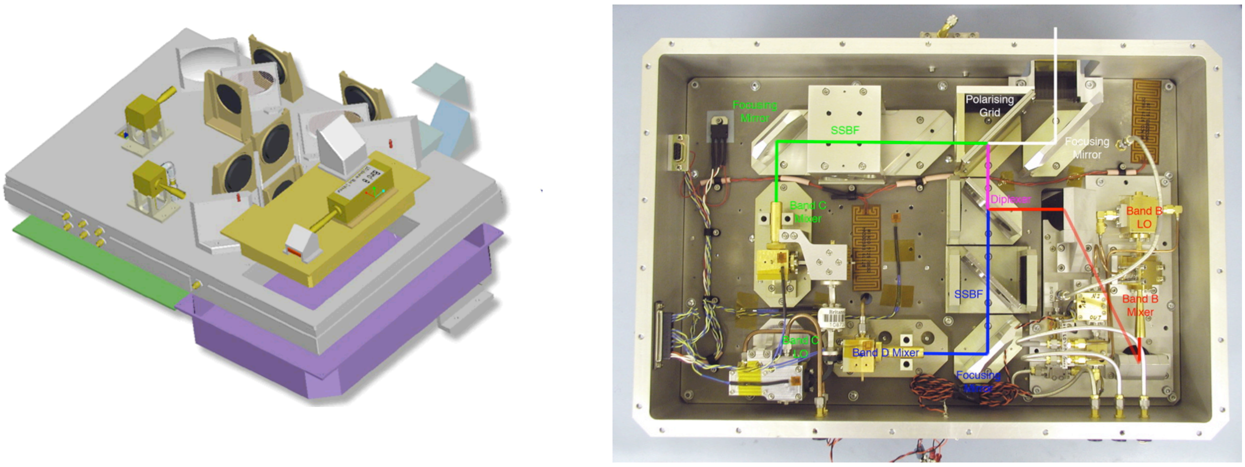


Figure 8 Quasioptics Module containing Quasi Optical Network and mm-wave mixers

Bands C and D employ mm-wave subharmonic mixers developed at RAL [4].

Channel demultiplexing and filtering of the image sidebands is performed using Frequency Selective Surface (FSS) elements developed at the Queen's University of Belfast. These consist of printed metallic arrays on fused silica substrates as described in [5].

The Band B receiver is a self-contained module developed by Radiometer Physics, Germany, under contract to ESA.

IF amplification and down conversion

The large instantaneous bandwidth of the MARSCHALS RF bands (between 7 and 12 GHz) means that the first IF has to be split into a number of sub-bands by a second down conversion stage in order to be compatible with presently available back end spectrometer technology.

As elsewhere in MARSCHALS, Commercial-Off-The-Shelf (COTS) IF components have been used, ruggedised where necessary to meet the unusual environmental requirements. The 12-24 GHz first IF is amplified, and then mixed down to a common second IF of 4-8 GHz before being passed to the three channeliser spectrometers each of 4 GHz bandwidth.

Channeliser spectrometers

Channeliser spectrometers developed by Com Dev Europe are used on MARSCHALS as they offer a cost-effective and low risk method of implementing wide instantaneous bandwidths with moderate resolution adequate for MARSCHALS UT measurements. In the case of MARSCHALS, there are a total of 60 channels, each with 200 MHz bandwidth, for a total bandwidth of 12 GHz.

Optical Cloud Monitor (OCM)

Millimetre-wave measurements are predicted to be much less affected by cirrus clouds in the UT than infrared measurements. However, the impact of cirrus is still expected to be significant in a small fraction of views. MARSCHALS therefore includes a near Infrared (NIR) camera imaging the atmospheric limb at 0.85 μm wavelength to help identify cloud free scenes and assess the impact of cloud where present.

Instrument control unit

The Instrument Control Unit (ICU) developed by Astrium UK is the MARSCHALS control, data acquisition and storage computer. It is based on commercial PC/104 cards, ruggedised by being shock mounted inside hermetically sealed pressurised canisters.

4. MARSCHALS FLIGHTS AND RESULTS

MARSCHALS made several test flights on board the Geophysica in 2005, funded by the European Space Agency (ESA) and the UK Natural Environment Research Council (NERC). It participated in its first scientific flights, funded by ESA, during the SCOUT-O3 campaign in Darwin in November-December 2005 during which it flew simultaneously with the MIPAS-STR and CRISTA-NF limb sounding instruments.

Results of joint flight with MIPAS-STR and CRIST-NF on 5/6 December 2005

The final local flight from Darwin during the SCOUT-O3 campaign was a dedicated remote sensing flight with the three limb sounders – MARSCHALS, MIPAS-STR and CRISTA-NF (Figure 9). Details of the flight are shown in Figure 10 & Figure 11.

Figure 9 Location of MARSCHALS, CRISTA-NF & MIPAS-STR on the Geophysica

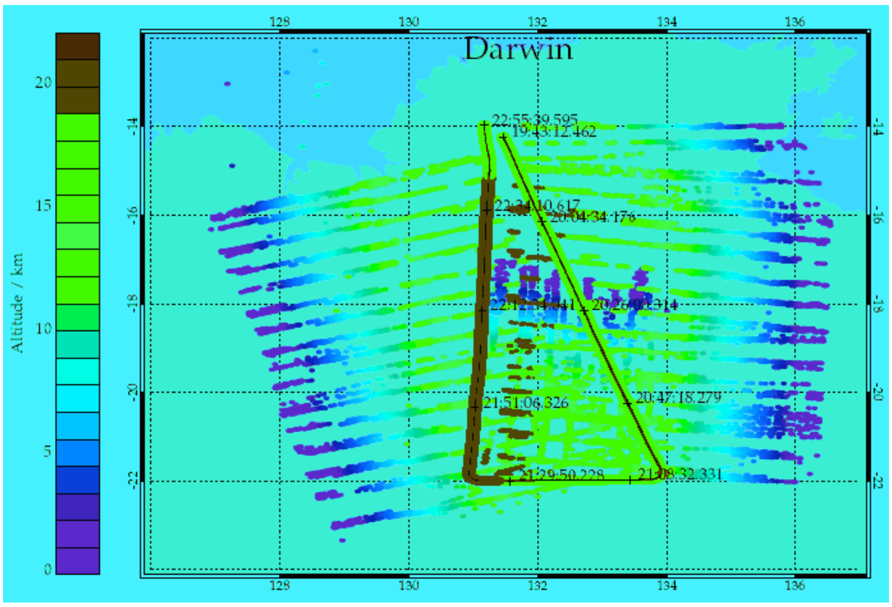


Figure 10 Flightplan on 5 December 2005.

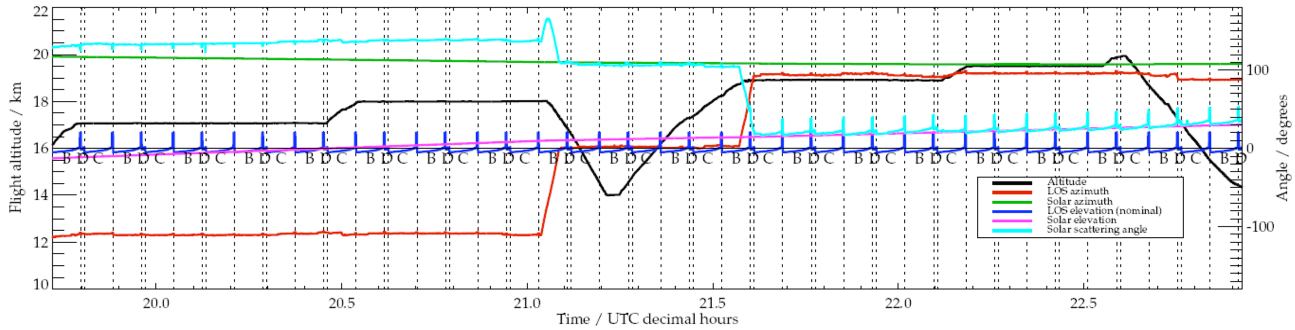


Figure 11 Altitude / angles / scan sequence for 5 December flight.

Figure 12 shows a plot of the CRISTA cloud index compared with a composite image from the MARSCHALS OCM during this flight. The CRISTA Cloud Index is a ratio of radiances in two (micro)windows. When the index approaches a value of 1 this indicates optically thick cloud in the mid-ir. For most of the flight, the mid-ir windows at altitudes below 16km are seen to be opaque due to cloud.

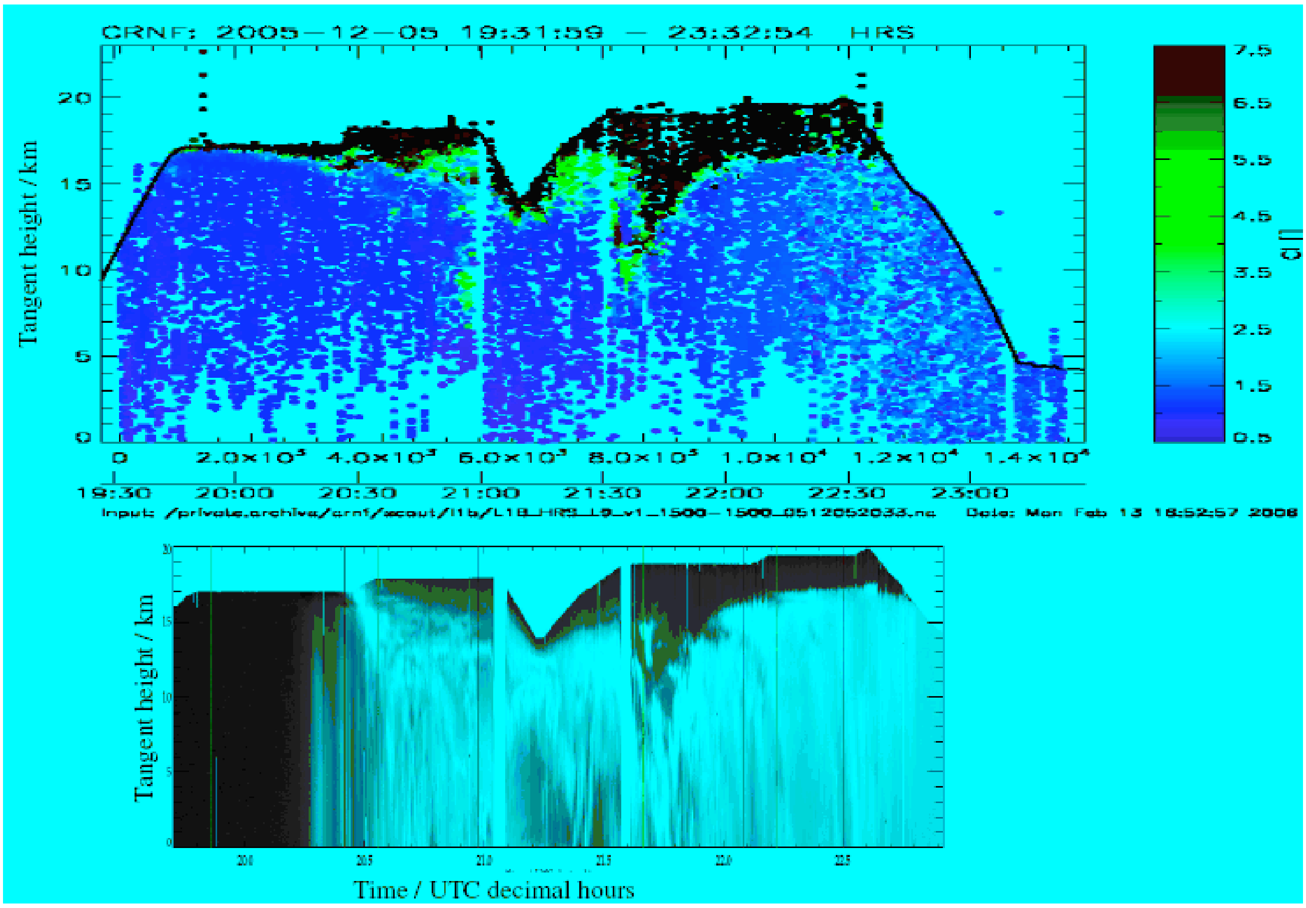


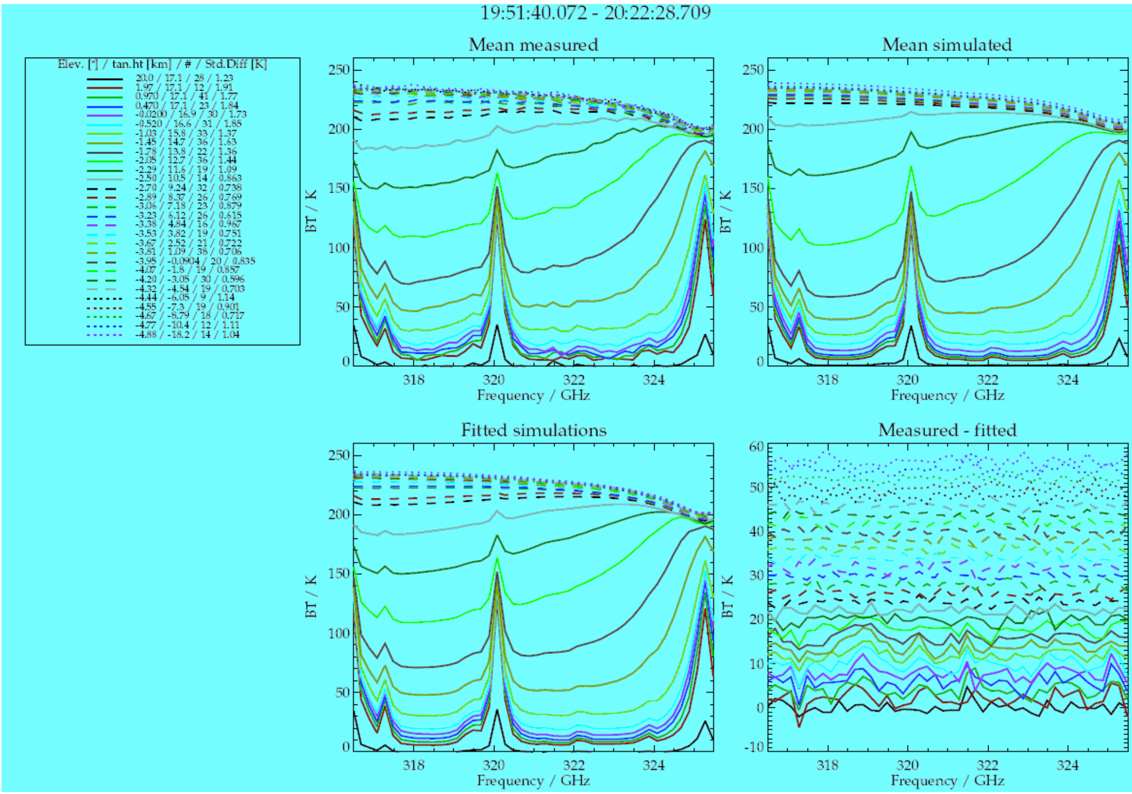
Figure 12 Top panel shows CRISTA-NF cloud flag (courtesy of the CRISTA-NF instrument team). Bottom panel shows MARSCHALS OCM data for the 5 December flight.

Figure 13 shows a comparison of MARSCHALS measured and simulated spectra (Band C – water) from legs 1-2 of the December 5/6 flight.

Flight data is still being analysed. However initial findings [6] from this flight are that MARSCHALS has clearly demonstrated observation of mm-wave spectral structure:

- To tangent heights <10km in the tropical upper troposphere when the tropopause is between 17-20km and

- Down to tangent heights several km below the tops of cirrus clouds which are opaque in mid-ir limb-views.
- In the lower stratosphere as well as the upper troposphere.



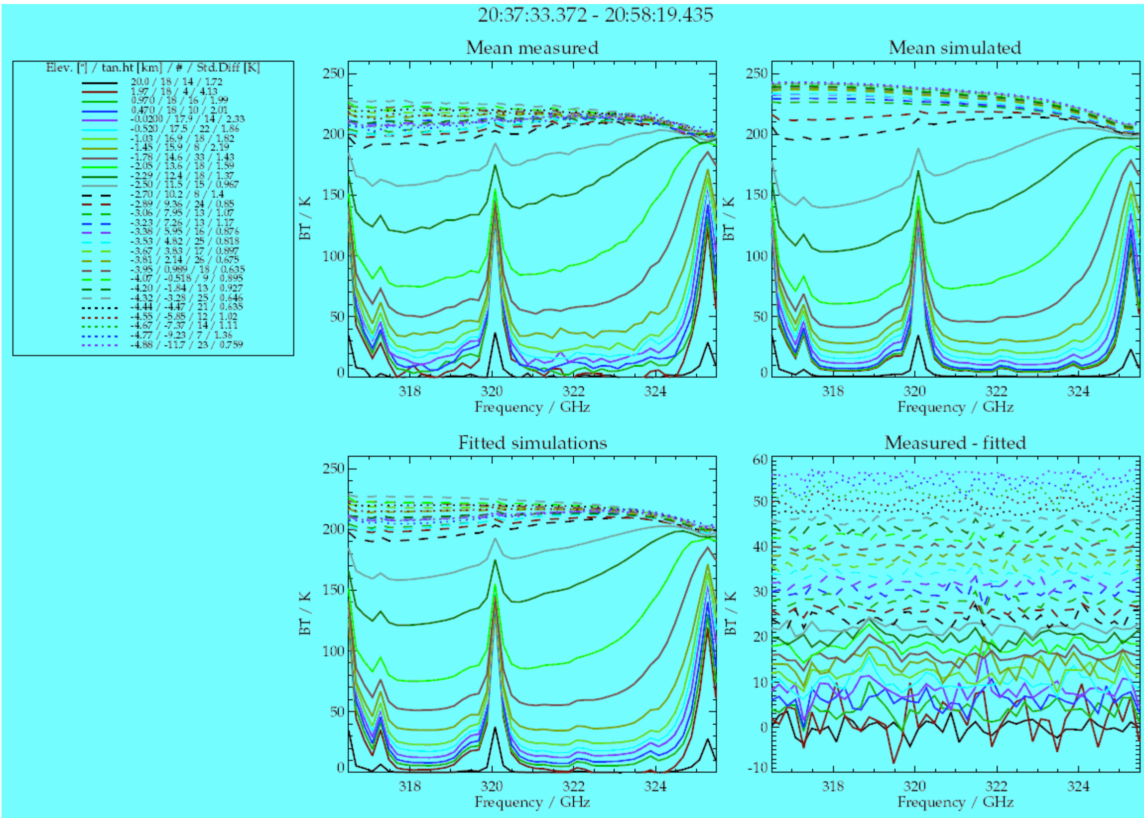


Figure 13 Measured, simulated, fitted and residual spectra for first 2 legs of 5 December flight: Band C.

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