SCIENCE INVESTIGATION OF THE ATMOSPHERIC CHEMISTRY SUITE ON EXOMARS TGO

O. Korablev, N.I. Ignatiev, A.A. Fedorova, A.Yu. Trokhimovskiy, A.V. Grigoriev, A.V. Shakun, *Space Research Institute (IKI), Moscow Russia (korab@iki.rssi.ru)*, **F. Montmessin,** *CNRS LATMOS, UVSQ, Guyancourt, France,* **F. Lefevre,** *CNRS LATMOS, UPMC, Paris France,* **F. Forget** *CNRS LMD, Paris France*, **The ACS Team.**

Introduction:

Studies of the atmosphere and climate of Mars are the main scientific objective of the ExoMars Trace Gas Orbiter (TGO) (Zurek et al., 2011). Following this goal for the joint Roscosmos-ESA configuration of the ExoMars project the Atmospheric Chemistry Suite (ACS) was proposed in 2011, selected by Russian Academy Section, and eventually accepted by ESA and Roscosmos as one of two Russian instruments onboard TGO. The ACS hardware was built in IKI (Space Research Institute in Moscow), using experience gained from Phobos Grunt developments (Korablev et al., 2012; 2013) and RUSALKA instrument operated on ISS (Korablev et al., 2011). ACS includes hardware contribution from LATMOS, France. The concept of the ACS experiment is described in Korablev et al. (2015), while design parameters of the ACS hardware are outlined in Korablev et al. (2014).

TGO orbits Mars since 19.10.2016, but the science operation phase will start in approximately one year from now after the completion of the aerobreaking phase. The report will focus on scientific objectives of the ACS experiment, its concept, methodology, and performances, expected or confirmed in flight.

Science Objectives:

1. Sensitive detection of minor atmospheric species. This is the primary goal of the ACS investigation. Trace atmospheric species will be detected in solar occultation covering most of the 0.7-17 μm spectral range with unprecedented resolving power. This will allow us to profile or to put stringent upper limits on the methane contents, possibly to detect SO_2, the gas of volcanic origin, and establish an accurate database on multiple atmospheric absorptions, including isotopologues of CO_2 and water, in particular D/H ratio. Sensitive detection of minor gases and isotopologues addresses global scientific problems related to Mars, such as volcanism, habitability, and climate evolution.

2. Monitoring of Mars climate. Thermal structure of the atmosphere from the surface up to ~60 km will be retrieved from CO_2 15-μm absorption band observed in nadir. Owing to the TGO spacecraft orbit, optimized for atmosphere and climate investigation, observations will consistently sample the diurnal cycle for the first time in orbit. Simultaneously, the surface temperature will be measured. From the same thermal-IR spectrum, dust and condensation aerosols will also be determined. Atmospheric water vapour column abundance will be measured in the near-IR range. Measuring the aerosol optical depth in a wide spectral range in solar occultations allows one to monitor the aerosol properties. Detecting the $O_2{}^1\Delta_g$ emission simultaneously with atmospheric H_2O would put constraints on photochemical models of Mars atmosphere.

The ACS experiment concept:

The ACS investigation is based on spectral analysis of solar radiation passed through the tamosphered scattered by the atmosphere, and emitted by the atmosphere. The spectral range covered by different channels of the instrument, as well as corresponding measured atmospheric constituents are shown in Fig. 1.

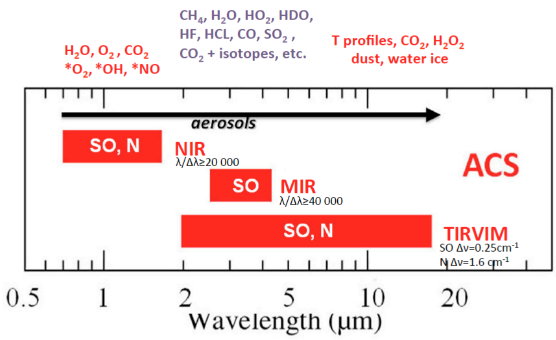

Fig. 1. Spectral coverage of three ACS channels, operating modes and main atmospheric targets.

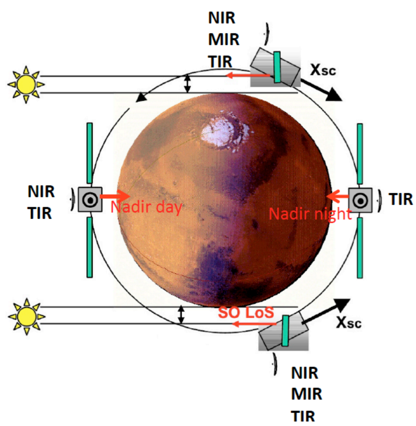

Fig. 2. Observations with different ACS channels from the final TGO orbit (h=400km, inclination 74°).

Two basic methods: nadir IR sounding and solar occultations are employed. It is also planned to observe day and night airglows, in nadir and on the limb of the planet in the near-IR range. These observations are schematically shown in Fig. 2.

Experimental Set-up:

The ACS instrument consists of three independent spectrometers and an electronics module with common mechanical, thermal and electrical interfaces. The development and manufacturing of a spectrometer system was carried out by IKI, with contribution from LATMOS (France), including key components provided by leading Russian and foreign manufacturers of optical components.

The near infrared channel (NIR) is a compact spectrometer operating in the range of 0.7–1.7 μm with a resolving power of $\lambda/\Delta\lambda \sim 20{,}000$. It is designed to operate in nadir and in solar occultation modes. The spectrometer employs an acousto-optic tunable filter (AOTF) to select diffraction orders in an echelle spectrometer. During one measurement cycle it is possible to register up to ten different diffraction orders, each corresponding to an instantaneous spectral range of 10-20 nm. The instrument features a long slit and an InGaAs array detector cooled by Peltier element, providing overall hyperspectral imaging capability. Additional details can be found in Trokhimovskiy et al. (2015a).

The mid-infrared channel (MIR) is an echelle-spectrometer with crossed dispersion, designed exclusively for solar occultation measurements in the 2.2–4.4 μm spectral range with a resolving power reaching 50,000. In order to achieve high spectral resolution a large (107×240 mm) echelle grating is used. Separation of the diffraction orders is carried out using a secondary steerable diffraction grating. For each elementary exposure of 0.5 s, a spectral range of up to 300 nm width is recorded, consisting of up to 20 adjacent diffraction orders imaged on the HgCdTe array detector cooled by Stirling machine (Fig. 3; Trokhimovskiy et al., 2015b).

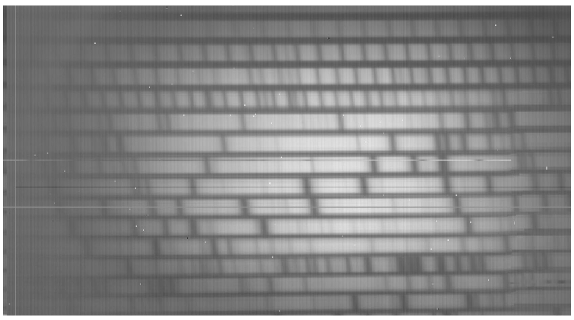

Fig. 3. One example frame of the ACS-MIR spectrometer. Sun is observed from the ground; the spectral range covered is 3.7-4.0 μm.

The thermal infrared range is covered by TIRVIM Fourier spectrometer. It has an aperture of ~5 cm, and is built on the principle of the double pendulum. The instrument measures the spectrum of the entire range of 1.7–17 μm with apodized spectral resolution varying from 0.2 to 1.6 cm^{-1} depending on observation mode. A single-pixel HgCdTe array detector with Stirling machine is used. Initially planned (Korablev et al., 2014) nadir detector optimized for the spectral range of 3.3 μm (characteristic for the methane absorption) has been cancelled during the implementation of the instrument. The principle goal of the TIRVIM channel remains the temperature sounding of the atmosphere in the 15-μm CO_2 band (Fig. 4). Around this band and in the adjacent shorter wavelength range, characteristic for atmospheric aerosols TIRVIM has ~10 times higher performances than those of PFS/Mars Express.

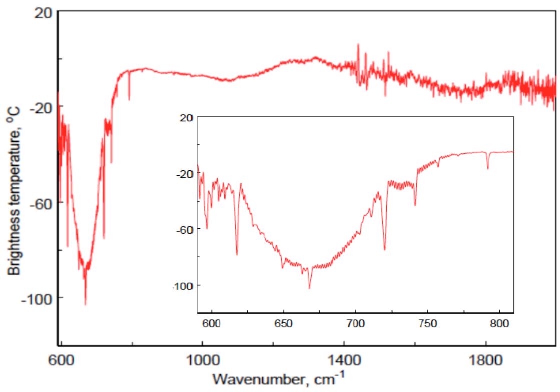

Fig. 4. Brightness temperature of Mars measured by ACS-TIRVIM from Mars capture orbit on 22.11.2016.

Conclusions:

The ACS instrument was built in a short time (funding released in January 2013; flight instrument delivered on 4 June 2015). After the launch, it has been operated during the Earth-Mars cruise, and from the Mars capture orbit (4 sol; 298 × 95 856 km). The functionality of all the three channels is confirmed. One more test observation of Mars before the aero-breaking phase is planned in March 2017. The instrument creation was funded by Roscosmos and CNES. The operations are supported by ESA and Roscosmos. The experiment Science team includes Co-Is and collaborators from Russia, France, Italy, Germany, Spain, UK, Belgium, Sweden, US, and Japan. OK, NI, AF, AT acknowledge support of Russian Government under the grant 14.W03.31.0017.

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