ATMOSPHERIC CHEMISTRY SUITE (ACS): A SET OF INFRARED SPECTROMETERS FOR ATMOSPHERIC MEASUREMENTS ON BOARD EXOMARS TRACE GAS ORBITER

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Introduction:

The studies of the Martian atmosphere and climate have been long time identified as the primary scientific goal of ExoMars Trace Gas Orbiter (TGO) [1], which is the follow up of the Mars Science Orbiter concept [2]. For the new configuration of the project based on ESA-Roscosmos cooperation, we have proposed a suite of spectroscopic instruments for the studies of the Mars atmosphere in the infrared spectral range – the Atmospheric Chemistry Suite (ACS). Selected by the Solar System Panel of the Space Council of Russian Academy of Science this instrument was introduced by Roscosmos as one of two Russian contributions to TGO, the second being collimated neutron detector FREND (Fine Resolution Epithermal Neutron Detector) [3]. The new set of TGO instruments has been discussed and approved by the Agencies during 2012; the final Agreement is signed in March, 2013. The new TGO payload includes four payloads: NOMAD [4], ACS, FREND, and CaSSIS (high-resolution color stereo camera).

ACS is the set of three spectrometers, covering in total range of 0.7-17 µm, being built in Space research Institute (IKI) in Moscow, Russia. Its design capitalizes on the previous developments of high technology readiness: two instruments built for unsuccessful Phobos-Grunt project [5-7] and one instrument flown at the ISS in 2009-2012 [8]. Some components/subsystems are contributed by German Institut für Planetenforschung (DLR) and LATMOS (CNRS) in France.

ACS includes three separate spectrometers (NIR, MIR, TIRVIM), sharing common mechanical and electrical interfaces. On the TGO spacecraft the instrument occupies the slot at the upper deck. ACS has several optical openings allowing observations in nadir (–Y in the spacecraft coordinate system), and in solar occultation, at 67° from –Y to –X in the XY plane. The common electronic block (BE) serves as a single electrical interface of the ACS to the spacecraft in terms of power, commands and data. Roughly two thirds of ACS's mass allocation of 33.5 kg is dedicated to larger channels, MIR and TIRVIM. The remaining mass is shared among the smaller NIR channel, the BE, the mechanical structure, and the thermal regulation system.

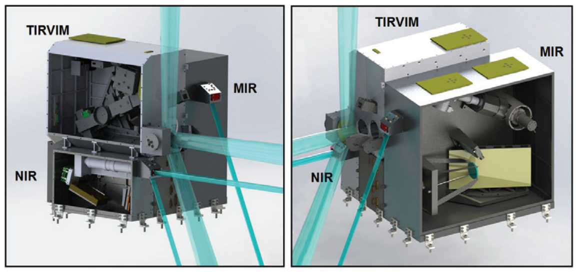

Figure 1. ACS architecture.

Further we will present each of the channels, their architecture and a very brief description of science goals, skipping mostly the relevant references and background.

NIR channel:

The ACS NIR channel employs the scheme of SOIR, combination of an echelle spectrometer and an acousto-optic tunable filter (AOTF) for the selection of diffraction orders. This scheme was originally proposed and prototyped for the measurements in the terrestrial atmosphere [9], and first implemented in space for the case of Venus [10]. The closest analogue of NIR is the RUSALKA instrument, flown on ISS in 2009-2012 [8]

ACS NIR is capable to perform nadir and occultation observations in 0.7-1.6 µm spectral range with R≥20,000 resolution. A red filter at the entrance right after the periscope mirror cancels out all intense sun wavelengths shorter than 0.7 µm. AOTF-telescope assembling with improved energy transmission and implemented slit form the FOV of approximately 20×0.02 arc min. The echelle spectrometer employs the Littrow auto-collimation scheme, in which an off-axis parabolic mirror plays the role of the collimating and the imaging elements. To enhance the sensitivity w.r.t. the previous design we use a higher slit in combination with 2D array detector allowing to capture the flux of the dispersed light along the full dimension of the slit. We adapt the space implementation of infrared camera module based on a TE-cooled InGaAs array of 640×512 pixels. The spectral range is extended w.r.t. standard InGaAs, and consists 0.4-1.7 µm. The detector's lines are averaged onboard into 5 bands of programmable position and height, each of 640 pixels long. The instrument can be programmed to register sequentially up to ten diffraction orders (10 different AOTF tunings, i.e. acoustic frequencies). The exposure time can be tuned from 1 ms to 1s depending on a observation regime. An onboard image averaging from 1 to 256 is also employed. For our custom size echelle grating (blaze angle 70°, 24.35 grooves/mm, useful area of 46×102 mm2) and following Nyqvist sampling (2 pixels per resolution element), the resolving power of the aberration-free spectrometer could reach almost R≈30,000. The aberrations of the off-axis parabolic collimator reduce the resolving power to ≥20,000, optimized at 1.2 µm.

NIR science. The smallest instrument of the suite is nevertheless dedicated to many scientific goals. As the SPICAM on MEX [11] NIR will perform the water vapour mapping in nadir and H2O vertical pro-filing in solar occultation mode from 1.38 µm band. High resolution and good performance will allow to carry out measurements in 100 times more accurate than SPICAM. H2O vertical profiles will be measured in the altitude range from 10 to 80 km depending on season and dust loading. Furthermore, the retrievement will be supported by aerosol and temperature profiles from the TIRVIM channel. Much of science is expected from the oxygen observations. High resolution NIR measurements of 1.27 µm O2(a1Δg).dayglow will supply indirect ozone observations on the dayside on nadir. On the night side NIR will be able to detect O2(a1Δg) nightglow which is a photochemical tracer of atomic oxygen recombination. In solar occulation mode, the O2 vertical profiles will be measured from the surface (in case of low dust activity) to the 40 km altitude based on 0.76 µm absorption band.

Together with MIR channel in solar occultation NIR will support the measurements of CO2 density profiles (based on 1.43 µm band) and aerosols characterization from 0.7 to 4 µm. The wide spectral range will allow not just determine aerosol particle sizes and density at different altitudes, but also distinguish between dust and ice particles. During the night side nadir observations, the ambitious goal of NIR is to perform a first mapping of OH airglow at the 1.45 µm and first observations of NO airglow at 1.224 µm for Mars. Preliminary estimations give SNR~5 and SNR~10 accordingly for these observations with 10 seconds averaging in nadir.

MIR channel:

The MIR channel is a cross-dispersion spectrometer working in 2.3-4.2 µm spectral range, covering simultaneously up to 300 nm per measurement. A cross-dispersion concept on echelle and ordinary diffraction grating allows acquisition of the wide wavelength domain at once. That provides a strategic advantage for maximizing the number of gaseous species detected simultaneously. Moving the second grating allows to switch from one group of the diffraction orders to another prior to a series of measurements, or alternating two desired positions during one measurement sequence. The concept of the cross-dispersion echelle instrument, which is widely accepted in astronomy, has been already employed in planetary missions with VIRTIS-H instrument presently in flight on Rosetta and Venus Express missions [12, 13].

Targeting very high spectral resolution the MIR channel operates in solar occultation only. A telescope with relative aperture of 1:3 forms the image of the solar disk on the slit. The FOV is determined by the slit and it consists 0.5×10 arc min (0.1×2.9 mrad). The spectral resolution of the spectrometer is fully slit-limited, and with a 30-µm slit the resolving power of $\lambda/\Delta\lambda \geq 50000$ at 3.3 µm is supported. Two secondary cross-dispersion diffraction gratings (plain, 150 and 300 grooves per mm) are mounted back-to-back on a stepper motor to change observed echelle orders. We have chosen two secondary gratings philosophy to switch between them depending on the long or short wavelength range we are on. Changing the position of the secondary grating in angular steps of 1.8°, from 10 to 30 echelle orders are available for simultaneous record depending on the wavelength. 100 steps are evidently used to switch between gratings prior measurements. The full spectral range is covered on 107 diffraction orders, from 142 to 248. For each observation detector area is covered by 10 to 30 stripes, each corresponding to single echelle diffraction order. The height of the stripes ranges from 150 to 200 µm depending on the wavelength. It is planned that there will be a possibility to change the position of the stepper motor during the occultation measurements, and to register two adjacent groups of diffraction orders.

The detector is a space-grade version of the standard Scorpio MW K508 Sofradir product, with optimized spectral range. The detection limit for trace gases is strongly limited by the S/N ratio, and at present right now the ACS engineering group is working on maximizing it. The "lower limit" for S/N is valued at 500. Given the complexity of the diffraction orders pattern, full detector frames will be transmitted to the ground, with lossless compression. However, similarly to NIR, the onboard averaging will be possible. Single data frame will be accumulated for each 0.5 or 1 second, stacking of a number of shorter exposures.

MIR science. The spectral range of MIR includes several CO2 absorption bands allowing to do measurements of density and temperature profiles from 10 to at least 140 km and isotopic ratios of

$^{13}CO_2/CO_2$, $CO^{18}O/CO_2$.

The D/H ratio in Martian atmosphere is measured only from the ground, with H_2O and HDO lines recorded separately. Also, the vertical profile of the HDO/H_2O ratio has never been measured. MIR is aimed to carry simultaneous measurements HDO in orders 3.42-3.74 µm and H2O between 3.18-3.45 µm, or/and recruiting H_2O data from NIR 1.38 µm band. D/H ratio and its profiles will give new information on water reservoirs, their history and cloud processes.

Another important goal is to do sensitive measurements of methane with detection threshold an order better that 1.3 ppbv (TLS on Curiosity rover, [14]). MIR will measure “at once” spectra in the echelle diffraction orders 187-173, corresponding to 3.18-3.45 µm. Right now detection limit for CH4 is better than 0.3 ppb for the worst case performance of S/N~500.

The short-wavelength side of MIR’s spectral range is extended to cover almost the whole carbon monoxide band. CO is a good tracer of airmass transport due to CO_2 condensation/sublimation and its observed abundances yet greatly differs from existing models. Observing strong and weak lines within the band will allow to retrieve concentrations at high and low altitudes.

Besides all that, MIR will be able to so sensitive search for a number of minor species, some yet undetected, some possibly related to volcanic or biologic activity: C_2H_2, C_2H_4, C_2H_6, HO_2, H_2O_2, H_2CO, HCl, SO_2, OCS etc.

The most of the MIR science tasks are also tackled by the TIRVIM channel and NOMAD [4], at different spectral resolution and using different instrument concepts. This redundancy increases the overall success of the TGO science mission.

TIRVIM channel:

In contrast to NIR and MIR abbreviations, which are self-explicit, TIRVIM stands for Thermal Infra-Red V-shape Interferometer Mounting, but also commemorates the initials of Vassilii Ivanovich Moroz, the IR astronomer and the leader of planetary school in IKI during 1968-2004, who introduced the Fourier-transform spectrometers and pursued their development in this institution [15].

TIRVIM is a 2-inch double pendulum Fourier-transform spectrometer covering in one interferometric channel the spectral range of 1.7-17 µm. The instrument capitalizes on previous developments of IKI in Fourier-spectrometers [16, 17, 18]. One may note its resemblance to PFS/Mars Express, however the mass of TIRVIM is 11 kg against 30 kg of PFS, and the two-channel design was not possible. The whole spectral range is covered in one channel with KBr beamsplitter. The principal improvements w.r.t. PFS are the maximal optical path difference (OPD) increased to as much as 6 cm, allowing to reach apodized spectral resolution of 0.2 cm–1, and two PV-MCT detectors (one for 1.7-17 µm, the other for 1.7-4.5µm), cooled by one Stirling-machine, thus increasing the sensitivity of the instrument by a factor of 50-80. The third detector, the pyroelectric one, will work at RT in 1.7-25µm range and serve as a redundant channel. All detectors can operate for both: Sun occultations and nadir measurements. For Sun observations with MCT detectors there is a special optical inlet ("periscope"), pointed at Sun. For nadir measurements TIRVIM has a single-axis pointer (scanner). The optical scheme of TIRVIM consists of the following main parts: Sun periscope, Scanner, blackbody simulator, interferometer, detector units with focusing optics and proximity electronics. The reference channel is based on 760-nm DFB Laser Diode. Scanner allows to point optical axis to nadir, to the Sun, to the internal blackbody and to the open space to obtain absolute radiometric calibration. On-board FFT and scissor mode for spectra will be implemented.

TIRVIM science. Being able to study all the minor species covered by the MIR channel in solar occultation mode, although at coarser spectral and spatial resolution, TIRVIM, with its capability to register a whole spectrum between 1.7 and 17 µm at a minimum spectral resolution of 0.12 cm^{-1}, is designed to address also a number of additional scientific tasks. First is the thermal sounding in the CO_2 15 µm band, which has been successfully carried out in a number of previous missions (IRIS/Mariner 9 [19], TES/MGS [20], PFS/Mars Express, e.g. [21]). The increased spectral resolution with respect to the previous measurements slightly improves both the altitude range (from the surface to 50-55 km) and the vertical resolution of the retrieved temperature profiles, which is of the order of several kilometers. Silicate dust and water ice absorption bands at 9 and 12 µm, respectively, are used to monitor simultaneously their optical depths. The Measurements at low spectral resolution in the whole spectral range both in nadir and solar occultation mode would be helpful in constraining physical properties of the clouds. Nadir mode is also perfect for ground surface and polar ice composition studies. Strong absorption bands of O_3 at 9.3 and H_2O_2 at 7.7 µm are not covered by other instruments of the mission and should be used to monitor the abundance of these species in the solar occultation mode at high spectral resolution.

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