ExoMars

ExoMars (Exobiology on Mars)

Overview Spacecraft Launch Mission Status Sensor Complement References

Background: Establishing whether life ever existed, or is still active on Mars today, is one of the outstanding scientific questions of our time. The ExoMars Program seeks to timely address this and other important scientific goals, and to demonstrate key flight and in situ enabling technologies underpinning European and Russian ambitions for future exploration missions. The ExoMars Program is a cooperative undertaking between ESA (European Space Agency) and the Russian federal space agency, Roscosmos. [1)]

Within ESA, ExoMars is an element of the Aurora Exploration Program, an optional program executed under the supervision of the Program Board for Human Spaceflight, Microgravity and Exploration (PBHME). However, the ESA Science Program also participates to ExoMars. The objective of the Aurora Program is to explore Solar System objects having a high potential for the emergence of life. Aurora aims to develop technologies and address scientific questions in a step-wise fashion, seeking to advance the level of technical and scientific readiness with each successive mission.

Within Roscosmos, ExoMars is part of the Russian federal space program and is supported by RAS (Russian Academy of Sciences).

To prepare for future exploration missions and to support the Program's scientific objectives, ExoMars will achieve the following technology objectives:

• EDL (Entry, Descent, and Landing) of a payload on the surface of Mars

• Surface mobility with a Rover

• Access to the subsurface to acquire samples

• Sample acquisition, preparation, distribution, and analysis.

In addition to these technology objectives already agreed in the Aurora Declaration, the following new technology objectives result from the cooperation with Roscosmos:

• Qualification of Russian ground-based means for deep-space communications in cooperation with ESA's ESTRACK

• Adaptation of Russian on-board computer for deep space missions and ExoMars landed operations

• Development and qualification of throttleable braking engines for prospective planetary landing missions.

The scientific objectives of ExoMars are:

• To search for signs of past and present life on Mars

• To investigate the water/geochemical environment as a function of depth in the shallow subsurface

• To study martian atmospheric trace gases and their sources.

In addition to these science objectives already agreed in the Aurora Declaration, the following new scientific objective results from the cooperation with Roscosmos:

• To characterise the surface environment.

The ExoMars Program consists of two missions, in 2016 and 2018. ESA and Roscosmos have agreed a well-balanced sharing of responsibilities for the various mission elements. [2)]

The **ExoMars 2016 mission** will be launched on a Roscosmos-provided Proton rocket. It includes the TGO (Trace Gas Orbiter) and the EDM (Entry, descent and landing Demonstrator Module), both contributed by ESA. The TGO will carry European and Russian scientific instruments for remote observations, while the EDM will have a European payload for in situ measurements during descent and on the martian surface.

In November 2013, ESA named the EDM **Schiaparelli** in honor the 19th century Italian astronomer Giovanni Schiaparelli (1835-1910). He observed bright and dark straight-line surface features on Mars which he called 'canali'. This term was mistakenly translated into English as 'canal' instead of 'channel', conjuring up images of vast irrigation networks constructed by intelligent beings living on Mars. The controversy ended in the early 20th century, thanks to better telescopes offering a clearer view of the planet. — The name was suggested by a group of Italian scientists to the president of the Italian space agency, ASI, who then proposed it to ESA. Italy is the largest European contributor to the ExoMars program. [3)]

The **ExoMars 2018 mission** will land a Rover, provided by ESA, making use of a DM (Descent Module) contributed by Roscosmos. The DM will travel to Mars on an ESA-provided CM (Carrier Module). Roscosmos will launch the spacecraft composite on a Proton rocket. The Rover will be equipped with a European and Russian suite of instruments, and with Russian RHUs (Radioisotope Heating Units). The Rover will also include a 2 m drill for subsurface sampling and a SPDS (Sample Preparation and Distribution System), supporting the suite of geology and life seeking experiments in the Rover's ALD (Analytical Laboratory Drawer). The Russian SP (Surface Platform) will contain a further suite of instruments, mainly concentrating on environmental and geophysical investigations. [4)]

NASA will also deliver important elements to ExoMars: The Electra UHF (Ultra-High Frequency) radio package on

TGO for Mars surface proximity link communications with landed assets (such as the Rover and Surface Platform); engineering support to EDM; and a major part of MOMA (Mars Organic Molecule Analyzer), the organic molecule characterization instrument on the Rover.

Diameter: 6794 km (about half the diameter of Earth)
Surface area: 145 million km^2 (about the same as the land area of Earth)
Gravity: 3.711 m s^{-2} (about one third of Earth's gravity)
Density: 3.93 g cm^{-3} (Earth: 5.51 g cm^{-3})
Average distance from the Sun: 227,940,000 km (1.52 times that of Earth)
Martian day (a 'sol'): 24 hours 37 minutes
Martian year: 669 sols or 687 Earth days
Average temperature: –55ºC (from –133ºC at the winter pole to +27ºC during summer)
Atmosphere: 95.32% carbon dioxide, 2.7% nitrogen, 1.6% argon, 0.13% oxygen
Atmospheric pressure at the surface: 6.35 mbar (less than one hundredth of Earth's atmospheric pressure)
Moons: Phobos: 27 x 22 x 18 km; ~6000 km from the surface; Deimos: 15 x 12 x 11 km; ~20,000 km from the surface

Table 1: An overview of some Mars parameters [5)]

Spacecraft of ExoMars 2016 mission:

The ExoMars mission is the first ESA-led robotic mission of the Aurora Program and combines technology development with investigations of major scientific interest. The main objectives of this mission are to search for evidence of methane and other trace atmospheric gases that could be signatures of active biological or geological processes and to test key technologies in preparation for ESA's contribution to subsequent missions to Mars. [6)]

The ExoMars 2016 mission spacecraft includes the following elements, all developed under the leadership of the prime contractor TAS-I (Thales Alenia Space-Italia). [7)]

• TGO (Trace Gas Orbiter), developed by Thales Alenia Space, France

• EDM, developed directly by TAS-I

• MSA (Main Separation Assembly), developed by RUAG.

The TGO accommodates scientific instrumentation for the detection of atmospheric trace gases and the study of their temporal and spatial evolution. In addition, it will provide telecommunications support for the 2016 mission, for the 2018 mission and possible other assets until 2022.

The objectives of the ExoMars 2016 mission are to:

1) Validate landing on the planet Mars with a demonstration capsule weighing about 600 kg, using a control system based on a radar altimeter, and with a carbon fiber shock absorber to attenuate the hard contact with the surface.

2) Gather as much information as possible during entry into the Martian atmosphere.

3) Carry out scientific sampling on the surface for a short period.

4) Observe the Martian atmosphere and surface for two years from the orbiter at an altitude of 400 km.

5) Provide the telecommunication support needed by the rover for the 2018 mission.

The EDM is mainly conceived to demonstrate EDL (Entry Descent and Landing) technologies for future planetary exploration missions. The following technologies are foreseen to be demonstrated:

• TPS (Thermal Protection System)

• PAS (Supersonic Parachute System)

• Radar technologies for ground relative altitude and velocity measurements

• Propulsion technologies for attitude control and braked landing

• Crushable material for impact load attenuation.

Figure 1: Artist's rendition of the deployed ExoMars 2016 Trace Gas Orbiter (TGO) and Schiaparelli – the entry, descent and landing demonstrator module (image credit: ESA, ATG medialag)

TGO (Trace Gas Orbiter)

The technical team behind the ExoMars spacecraft involves companies across more than 20 countries. The prime contractor, Thales Alenia Space Italia, is leading the industrial team building the spacecraft (Ref. 5)). As a part of the European industrial team, OHB System AG was responsible for developing the core module of the TGO, which comprises the structure as well as the thermal and propulsion system for the 2016 mission. OHB as member of the core industrial team, is responsible for the major German contribution to ExoMars.

Spacecraft	3.2 m x 2 m x 2 m with solar wings (20 $m^{2)}$ spanning 17.5 m tip-to-tip providing approximately 2000 W of power
Launch mass	4332 kg (including 112 kg of science payload and 600 kg Schiaparelli)
Propulsion	Bipropellant, with a 424 N main engine for Mars orbit insertion and major maneuvers
Power	In addition to power generated by the solar wings, 2 lithium-ion batteries will be used to cover eclipses, with ~ 5100 Wh total capacity
Communication	65 W X-band system with 2.2 m diameter high-gain antenna and 3 low-gain antennas for communication with Earth; Electra UHF-band transceivers (provided by NASA) with a single helix antenna for communication with surface rovers and landers
Science instrument package	ACS (Atmospheric Chemistry Suite); CaSSIS (Color and Stereo Surface Imaging System); FREND (Fine Resolution Epithermal Neutron Detector); NOMAD (Nadir and Occultation for Mars Discovery)
Nominal mission end	2022

Table 2: Main technical characteristics of the ExoMars Trace Gas Orbiter

NASA's participation in the 2016 ExoMars Trace Gas Orbiter includes two "Electra" telecommunication radios. Used successfully on NASA's Mars Reconnaissance Orbiter, Electra acts as a communications relay and navigation aid for Mars spacecraft. Electra's UHF radios support navigation, command, and data-return needs. [8)]

TGO's Electra radios use a design from NASA/JPL with special features for relaying data from a rover or stationary lander to an orbiter passing overhead. Relay of information from Mars-surface craft to Mars orbiters, then from Mars orbit to Earth, enables receiving much more data from the surface missions than would otherwise be possible.

As an example of Electra capabilities, during a relay session between an Electra on the surface and one on an orbiter, the radios can maximize data volume by actively adjusting the data rate to be slower when the orbiter is near the horizon from the surface robot's perspective, faster when it is overhead.

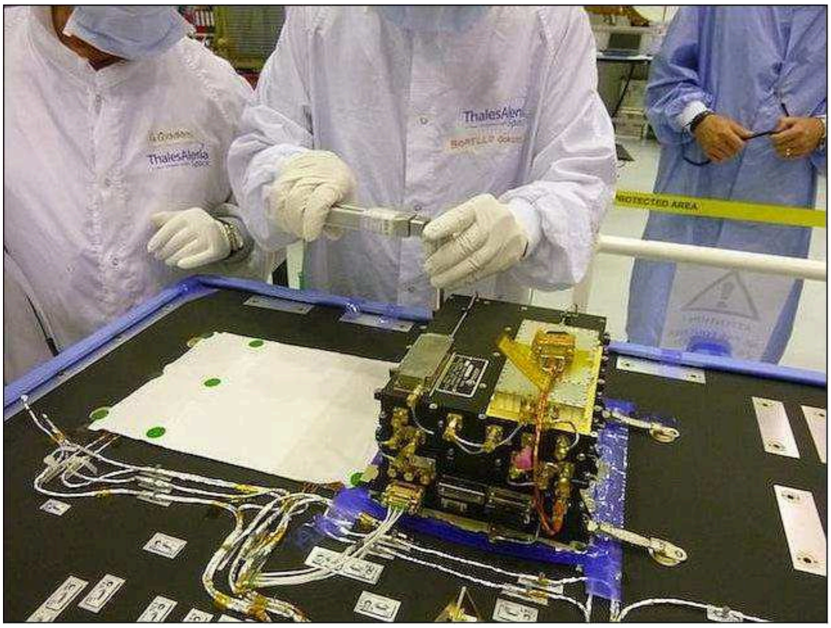

Figure 2: This image shows a step in installation and testing of the first of the orbiter's Electra radios, inside a clean room at Thales Alenia Space, in Cannes, France, in June 2014 (image credit: NASA/JPL-Caltech /ESA/TAS) [9]

RCS (Reaction Control System): TGO requires a challenging propulsion subsystem. The TGO RCS will provide the thrust to the spacecraft for all initial trajectory corrections, DSMs (Deep Space Maneuvers) during the cruise phase to Mars and also the high thrust necessary for the final MOI (Mars Orbit Insertion) maneuver. Subsequently, it shall perform 3-axis attitude control of the TGO once in orbit around Mars for the remainder of its seven year lifetime. [10]

The selected RCS is a helium-pressurized bi-propellant propulsion system utilizing MMH (Monomethylhydrazine) as the fuel and mixed oxides of nitrogen (MON-1) as the oxidizer. The architecture is derived from previous flight proven European applications, however the detailed layout is unique and driven by the specific configuration of the TGO spacecraft and the redundancy needs of the ExoMars 2016 mission.

All RCS architecture and engineering activities have been performed by OHB-System (including all subsystem analyses), while Airbus Defence and Space has responsibility for the mechanical configuration, procurement and manufacturing of equipment, integration and acceptance test to ensure that the system requirements defined by TAS-F are satisfied. The subsystem test program has been defined by OHB-System and performed by Airbus DS at the Airbus DS, OHB-System and TAS facilities. Out of the 92 components comprising the flight RCS, 67 are manufactured by Airbus DS including all tanks and thrusters.

Figure 3: The ExoMars Trace Gas Orbiter and Schiaparelli (top) during vibration testing in 2015, the high-gain antenna is on the right (image credit: ESA, S. Corvaja)

Schiaparelli / EDM (Entry, Descent and Landing Demonstrator Module)

Landing on Mars: Despite a number of prominent US successes since the 1970s, landing on Mars remains a significant challenge. As part of the ExoMars program, a range of technologies has been developed to enable a controlled landing. These include a special material for thermal protection, a parachute system, a radar altimeter system, and a final braking system controlled by liquid-propellant retrorockets. Schiaparelli is designed to test and demonstrate these technologies, in preparation for future missions (Ref. 5).

Three days before reaching Mars, Schiaparelli will separate from TGO and coast towards the planet in hibernation mode, to reduce its power consumption. It will be activated a few hours before entering the atmosphere at an altitude of 122.5 km and at a speed of 21 000 km/h. An aerodynamic heatshield will slow the lander down such that at an altitude of about 11 km, when the parachute is deployed, it will be travelling at around 1650 km/h.

Schiaparelli will release its front heat shield at an altitude of about 7 km and turn on its radar altimeter, which can measure the distance to the ground and its velocity across the surface. This information is used to activate and command the liquid propulsion system once the rear heatshield and parachute has been jettisoned 1.3 km above the surface. At this point, Schiaparelli will still be travelling at nearly 270 km/h, but the engines will slow it to less than 2 km/h by the time it is 2 m above the surface. At that moment, the engines will be switched off and Schiaparelli will freefall to the ground, where the final impact, at just under 11 km/h, will be cushioned by a crushable structure on the base of the lander.

Although Schiaparelli will target the plain known as Meridiani Planum in a controlled landing, it is not guided, and the module has no obstacle-avoidance capability. It has, however, been designed to cope with landing on a terrain with rocks as tall as 40 cm and slopes as steep as 12.5º.

Because Schiaparelli is primarily demonstrating technologies needed for landing, it does not have a long scientific mission lifetime: it is intended to survive on the surface for just a few days by using the excess energy capacity of its batteries. However, a set of scientific sensors will analyse the local environment during descent and after landing, including performing the first measurements of atmospheric particle charging effects, to help understand how global dust storms get started on Mars. A communication link with TGO will provide realtime transmission of the most important operational data measured by Schiaparelli during its descent. Shortly after Schiaparelli lands, TGO will start a main engine burn and will return over the landing site only four sols later. In the meantime, the remainder of the entry, descent and landing data, along with some of the science instrument data, will be sent to Earth via ESA's Mars Express and NASA satellites already at Mars.

Schiaparelli Design:

Schiaparelli builds on a heritage of designs that have been evaluated and tested by ESA during earlier ExoMars studies. The module accommodates a series of sensors that will monitor the behaviour of all key technologies during the mission. These technologies include a special material for thermal protection, a parachute system, a radar Doppler altimeter system, and a braking system controlled by liquid propulsion. The data will be sent back to Earth for post-flight reconstruction in support of future European missions to Mars.

Diameter	2.4 m in diameter with heatshield, 1.65 m without heatshield
Mass	600 kg
Heat shield material	Norcoat Liege
Structure	Aluminum sandwich with CFRP (Carbon Fiber Reinforced Polymer) skins
Parachute	Disk-Gap-Band canopy, 12 m diameter
Propulsion	3 clusters of 3 hydrazine engines (400 N each), operated in pulse-modulation
Power	Batteries
Communication	UHF link with the ExoMars Orbiter (with 2 antennas)

Table 3: Main technical characteristics of Schiaparelli – the ExoMars EDM (Entry, Descent and Landing Demonstrator Module)

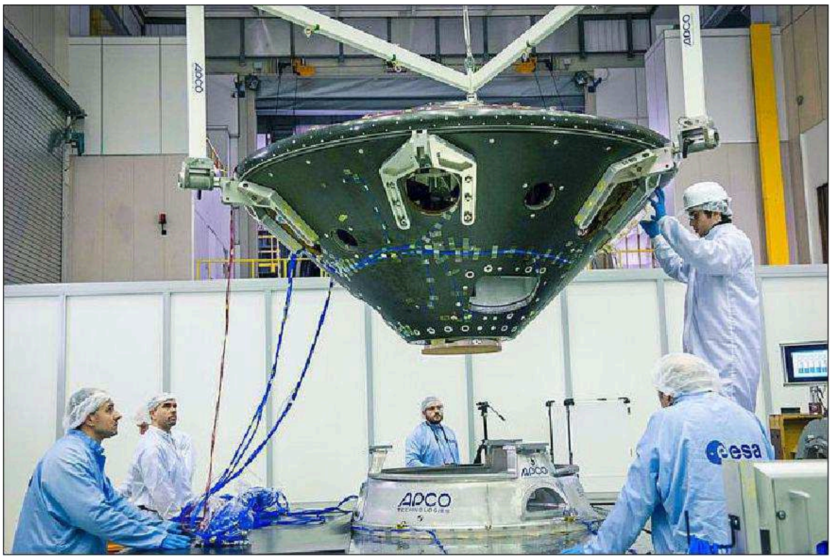

Figure 4: Photo of the Schiaparelli/EDM structural model which is being lowered onto the Multishaker at ESA/ESTEC (image credit: ESA, A. Le Floc'h, Ref. 3))

Launch preparations: In late December 2015, the ExoMars 2016 Trace Gas Orbiter and Schiaparelli (the entry, descent and landing demonstrator module) travelled aboard two Antonov 124 cargo jets from Turin, Italy, to the Baikonur Cosmodrome in Kazakhstan to be readied for launch in March. [11)]

Since then, engineering teams, totaling about 65 people, from Thales Alenia Space (Italy and France), the ExoMars project team, instrument teams, and specialists from the Baikonur Cosmodrome have been steadily working through an intensive and painstaking program of final testing and preparation of the two spacecraft, which at 4.300 kg will be the heaviest spacecraft composite ever to be sent to Mars.

All this has to be completed in time for a launch scheduled for 14 March at the beginning of the 12-day launch window for this mission.

Central to the launch campaign activities is the cleanroom. Almost everything in the cleanroom has been transported from Europe for this launch campaign – hence the need for a third Antonov flight. In addition to the specialist lifting equipment and the ground support trolleys needed to move the two spacecraft, the teams have also had to prepare a dedicated ISO 7 environment cleanroom tent, within the "normal" ISO 8 cleanroom environment, for handling Schiaparelli which, being a Mars lander, must be regularly sampled to check that it satisfies the planetary protection regulations. For analysis of these samples a dedicated microbiological laboratory was brought from Turin and installed close to the cleanroom area.

The readying of the TGO (Trace Gas Orbiter) has included a series of system health checks, such as checking that signals could be sent to all spacecraft units and that they responded. The health of the payload – the four science instruments, ACS, CaSSIS, FREND and NOMAD – was checked in a similar manner by verifying that commands could be sent to them and that these commands were carried out. The flight model of FREND was swapped for the flight spare model.

Another important test that has been completed was with the Trace Gas Orbiter and the launch vehicle adapter. Mechanical fit checks and separation tests had already been done in Cannes last year. Here in Baikonur, the team checked the mechanical connections, and also verified that all electrical circuits were completed.

In parallel, Schiaparelli is also being prepared for launch and is subject to tests similar to those performed on the orbiter. The instruments, sensors (DREAMS and COMARS+) and systems have all been thoroughly checked. A leak test has been carried out. Engineers have uploaded the final software and charged the batteries - since Schiaparelli has no solar panels the fully charged batteries are essential for the surface operations. [12)]

The mating of the TGO (Trace Gas Orbiter) and Schiaparelli began on 12 February, 2016 with the two spacecraft having been transferred into the fuelling area, where a mounting platform surrounding the orbiter facilitates the activities that need to be done about 4 m off the ground.

TGO and Schiaparelli are mechanically linked with the MSA (Main Separation Assembly), which attaches to TGO with 27 screws. The MSA holds onto Schiaparelli with three separation mechanisms comprising compressed and angled springs that are held by NEAs (Non-Explosive Actuators). When the NEAs are released on 16 October, as the spacecraft approaches Mars, Schiaparelli will be gently pushed away from TGO, at the same time being imparted with a rotation that will serve to stabilize its atmospheric entry.

Figure 5: The ExoMars 2016 Trace Gas Orbiter (with Schiaparelli on top) being fuelled at the Baikonur Cosmodrome in Kazakhstan (image credit: ESA) [13)]

Legend to Figure 5: This spacecraft has one fuel tank and one oxidizer tank, each with a capacity of 1207 liter. When fuelling is complete, the tanks will contain about 1.5 ton of MON (mixed oxides of nitrogen) and 1 ton of MMH (monomethylhydrazine). The propellant is needed for the main engine and the 10 thrusters (plus 10 backup thrusters) that are used for fine targeting and critical maneuvers.

Figure 6: The ExoMars 2016 spacecraft, comprised of the Trace Gas Orbiter and Schiaparelli, are now sealed inside the rocket fairing (image credit: ESA, B. Bethge) 14) 15)

Legend to Figure 6: On March 2, 2016, the Breeze upper stage and spacecraft were encapsulated together within the two fairing halves. Prior to the encapsulation, they were tilted horizontally and the first fairing half was rolled underneath the spacecraft and Breeze, on a track inside the cleanroom. The second fairing half was then lowered into place by means of an overhead crane, encapsulating the payload.

Figure 7: Proton-M rocket with ExoMars 2016 Trace Gas Orbiter and Schiaparelli module at the launch pad in Baikonur, Kazakhstan (image credit: ESA, B. Bethge) 16)

Launch: The European-Russian ExoMars (TGO and the EDM Schiaparelli lander) satellite was launched on March 14, 2016 (09:31 GMT) on a Proton-M/Briz vehicle from the Baikonur Cosmodrome, Kazakhstan. The launch provider was ILS (International Launch Services) KhSC (Khrunichev State Research and Production Space Center). 17) 18) 19)

Orbit: The SCC (ExoMars Spacecraft Composite) will be inserted into a T-2 transfer trajectory to Mars. The arrival on Mars is planned on Oct. 19, 2016 after a 9-month cruise phase.

During the cruise phase, the TGO will support all necessary operations and communications with Earth, and will provide the EDM (Schiaparelli) with the required power/energy. During this period, the EDM will be mostly in hibernation mode to minimize the TGO energy consumption, and nominally will be switched on only for three checkouts: the EDM commissioning checkout few days after the launch, the mid-cruise checkout to verify the EDM health status after the DSM (Deep Space Maneuver), and the preseparation checkout few hours before the separation from the TGO.

The EDM will be released by the TGO three days before the arrival at Mars (i.e. on Oct. 16th, 2016) by means of a 3-points spin-up separation mechanism (MSA). The separation provides a relative velocity higher than 0.3 m/s and a spin rate of 2.5 rpm. The spin rate will allow the EDM for maintaining the attitude needed to reach the Mars atmosphere EIP (Entry Interface Point) with a null angle of attack. The duration of the EDM coast phase (3 days), driven by the TGO need to have enough time to correct its orbit after the EDM separation and prepare the critical MOI ()Mars Orbit Injection) maneuver, is challenging for the EDM as the dispersions, coming from the navigation and from the separation mechanism, will propagate for quite a long time, by increasing the trajectory dispersions at Mars EIP.

During the coast phase, the EDM will be mainly in hibernation mode, to minimize the energy consumption from its batteries. Shortly before the arrival at the Mars EIP, the EDM will wake up from the hibernation to prepare the EDL phase.

The ExoMars Orbiter, TGO, will be inserted into an elliptical orbit around Mars and then sweep through the atmosphere to finally settle into a circular, approximately 400 km altitude orbit ready to conduct its scientific mission; inclination = 74º, period of ~2 hours.

TGO will also serve as a data relay for the second ExoMars mission, comprising a rover and a surface science platform, planned for launch in 2018. It will also provide data relay for NASA rovers.

Mission status:

• April 14, 2016: The ESA–Roscosmos ExoMars spacecraft TGO and Schiaparelli are in excellent health following launch last month, with the orbiter sending back its first test image of a starry view taken en route to the Red Planet. In the weeks following liftoff on 14 March, mission operators and scientists have been intensively checking the TGO (Trace Gas Orbiter) and the Schiaparelli entry, descent, and landing demonstrator to ensure they will be ready for Mars in October. [20)]

- TGO's control, navigation and communication systems have been set up, the 2.2 m diameter high-gain dish is already providing a 2 Mbit/s link with Earth, and the science instruments have undergone initial checks.

- Once orbiting Mars, TGO will embark on a mission to measure the abundance and distribution of rare gases in the atmosphere with its sophisticated sensors. Of particular interest is methane, which could point to active geological or biological processes on the planet.

- "All systems have been activated and checked out, including power, communications, startrackers, guidance and navigation, all payloads and Schiaparelli, while the flight control team have become more comfortable operating this new and sophisticated spacecraft," says Peter Schmitz, ESA's Spacecraft Operations Manager.

- On 7 April, TGO's high-resolution camera was switched on for the first time, acquiring its first images of space.

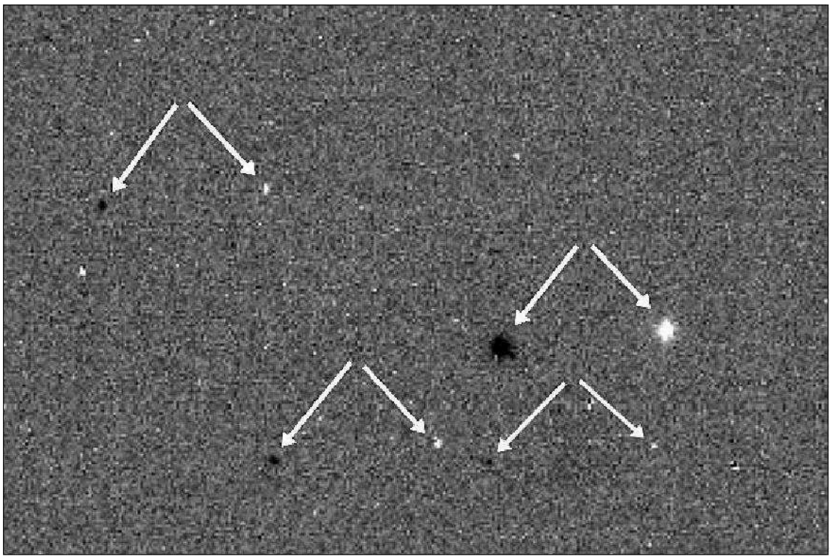

Figure 8: The image was taken by the CaSSIS (Color and Stereo Surface Imaging System), and points to a randomly selected portion of the sky close to the southern celestial pole (image credit: ESA/Roscosmos /CaSSIS)

Legend to Figure 8: The picture shows the result of taking one CaSSIS frame, turning the camera's rotation mechanism, and then taking another. By subtracting the two frames, a series of bright and dark spots are seen, all equally offset from each other, demonstrating that these are positive and negative images of the same stars. The FOV (Field of View) is 0.2º in the horizontal direction, and is a subset of a larger image, extracted for this purpose to show the stars at a reasonable size. The arrows indicate the offset star positions. [21)]

In operation at Mars, about 400 km above the planet, CaSSIS will sweep out a swath as TGO approaches it, then turn the rotation mechanism by 180º and image the same swath as it recedes. By doing so, CaSSIS will make stereo images of the surface.

• March 23, 2016: After the critical first few days in space, TGO is performing flawlessly. Over the next two weeks the ExoMars team will continue to check and commission its systems, including the power, communications, star trackers, and the guidance and navigation system. Schiaparelli, which is hitching a ride to Mars with TGO, will also be thoroughly checked in the coming weeks. [22)]

- On March 17, the mission control team had declared the LEOP (Launch and Early Orbit Phase) complete.

- In June, the science control center at ESAC (European Space Astronomy Center) near Madrid, Spain, will start working with the instrument teams at their various institutes, and the Roscosmos science operations center, to perform a mid-cruise checkout of TGO's instruments.

•Some 12 hours after launch, and after a very precise orbital delivery from the Russian Proton–Breeze rocket, ground stations in Africa, Spain and Australia began receiving the spacecraft's initial signals, confirming that TGO was alive and well, and had started its automatic sequence, switching itself on, orienting its antenna towards Earth and deploying the solar wings.

• The Breeze-M upper stage, with ExoMars attached, then completed a series of four burns before the spacecraft was released at 20:13 GMT.

• Following separation of Proton's first and second stages, the payload fairing was released. The third stage separated nearly 10 minutes after liftoff.

Figure 9: Artists rendition of the ExoMars spacecraft separation from the Briz (Breeze) fourth stage (image credit: ESA)

Launch	14 March 2016
Schiaparelli – Trace Gas Orbiter separation	16 October 2016
Trace Gas Orbiter insertion into Mars orbit	19 October 2016
Schiaparelli enters Martian atmosphere and lands on the target site	19 October 2016
Schiaparelli science operations begin	19 October 2016
TGO (Trace Gas Orbiter) changes inclination to science orbit (74°)	December 2016
Apocenter reduction maneuvers (from the initial 4-sol orbit to a 1-sol orbit)	December 2016
Aerobraking phase (Trace Gas Orbiter lowers its altitude to 400 km circular orbit)	January 2017 - November 2017
TGO science operations begin. (In parallel, TGO will start data relay operations to support NASA landers on Mars.)	December 2017
Superior solar conjunction (critical operations are paused while the Sun is between Earth and Mars)	11 July - 11 August 2017
Start of the TGO data relay operations to support communications for the rover mission and for the surface science platform	15 January 2019
End of Trace Gas Orbiter mission	December 2022

Table 4: Planned ExoMars 2016 mission phases overview [23)]

Sensor complement of TGO (ACS, CaSSIS, FREND, NOMAD)

With a science payload of four instruments , the TGO will investigate trace gases – those gases that are present in small concentrations in the atmosphere, making up less than 1 per cent of it. There will be particular focus on hydrocarbons and sulphur species, some of which could be signatures of active biological or geological processes, at present or in the past.

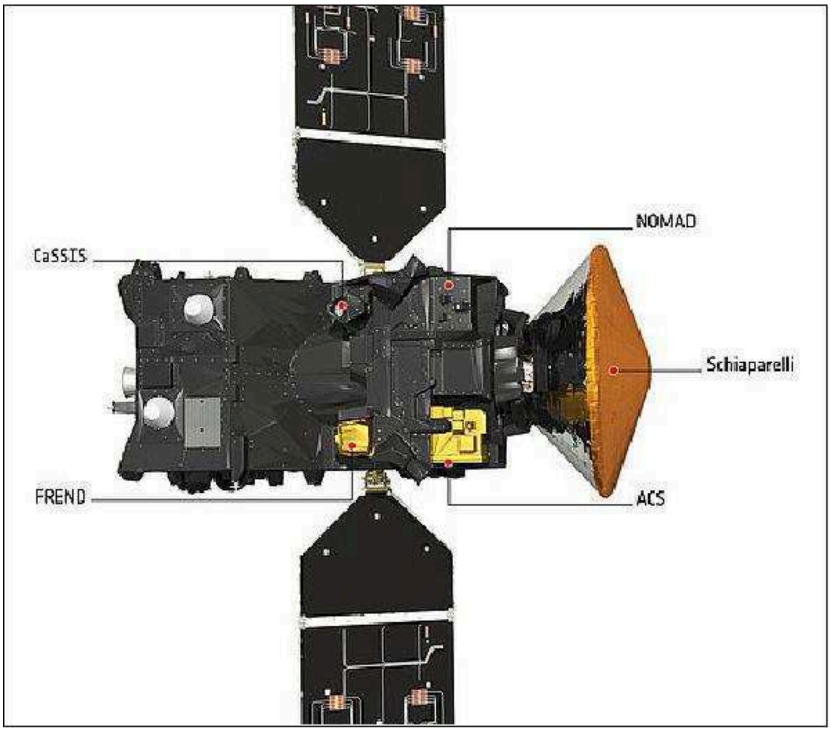

Figure 10: Artist's rendition of the ExoMars 2016 TGO (Trace Gas Orbiter) and Schiaparelli along with the sensor allocations (image credit: ESA, ATG medialab)

ACS (Atmospheric Chemistry Suite)

ACS is a suite of three infrared spectrometers to investigate the chemistry, aerosols, and structure of the atmosphere. The package is part of the Russian contribution to the ExoMars ESA-Roscosmos mission. ACS will complement NOMAD by extending the coverage at infrared wavelengths. PI (Principal Investigator): Oleg Korablev, Space Research Institute (IKI), Moscow, Russia. Next to IKI, the following institutions are collaborating on ACS: Moscow Institute of Physics and Technology;Main Astronomical Observatory, Kyiv, Ukraine; and the National Research Institute for Physical-technical and Radiotechnical Measurements (VNIIFTRI), Moscow Region. [24] [25] [26] [27]

ACS is the set of three spectrometers (NIR, MIR, TIRVIM), covering in total range of 0.7-17 µm developed by IKI. Its design capitalizes on the previous developments of high-technology readiness: two instruments built for the unsuccessful Phobos-Grunt project and one instrument flown on the ISS (International Space Station) in the timeframe 2009–2012.12. Some components/subsystems were contributed by the DLR German Aerospace Center) Institut für Planetenforschung and by LATMOS (CNRS) in France.

The three ACS spectrometers share common mechanical, thermal, and electrical interfaces. The ACS architecture and its concept design are shown in Figure 11. ACS has several optical openings allowing observations in nadir (-Y in the spacecraft coordinate system), and in solar occultation, at 67º from -Y to -X in the XY plane, and possibly on the limb (using nadir apertures). The accuracy of spacecraft attitude control is ±1 mrad. The main opening of NIR is pointed to the nadir direction (-Y). The auxiliary solar port of NIR and the only opening of MIR (Mid-Infrared) are pointed to the sun. The thermal infrared channel (TIRVIM) is equipped with a one-dimensional (1D) scanner/positioner rotating its FOV (Field of View) in the XY plane from +X to almost -X. It allows us to observe nadir, internal blackbodies, and the open space, which are necessary for absolute calibration of TIRVIM in the IR. TIRVIM has also a separate solar occultation port.

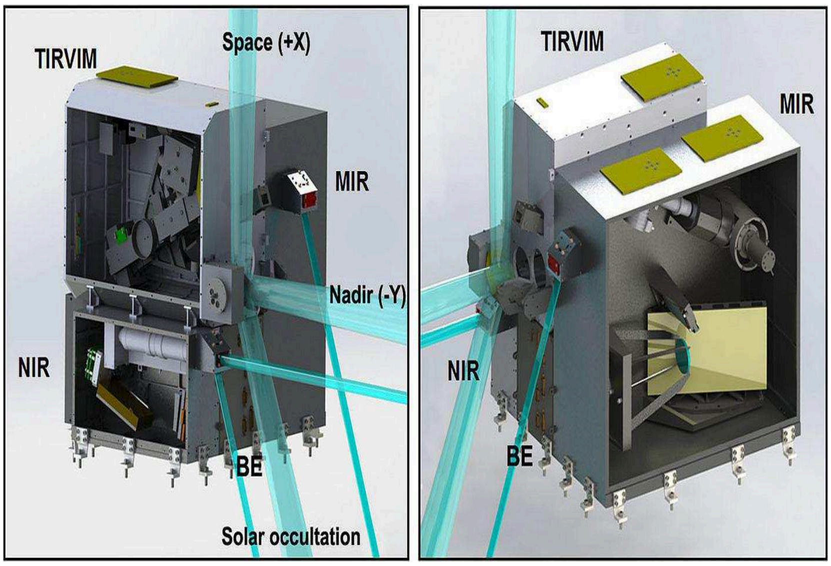

Figure 11: The concept design of ACS. Suite consists of four blocks: the NIR channel, the MIR channel, the

TIRVIM channel, and the electronic block. The yellow blocks designate the instrument's radiators. The pointing directions of the ACS channels are shown (image credit: IKI)

The ACS block diagram is shown in Figure 12. The common BE (Electronic Block) serves as a single electrical interface of the ACS to the spacecraft in terms of power, commands, and data. The power interface includes the main power switch, power conditioning, and the specific switches for each scientific channel. The final power distribution is done in the channels using regulated voltage lines from the BE. The command and data interfaces to TGO are MIL1553 and SpaceWire, respectively. The fully redundant BE electronics feature an FPGA (Field-Programmable Gate Array) and include a 32 GB of flash memory. The control electronics units of each channel are redundant as well. The data and command interfaces between the BE and the scientific channels are of the type low-voltage differential signaling.

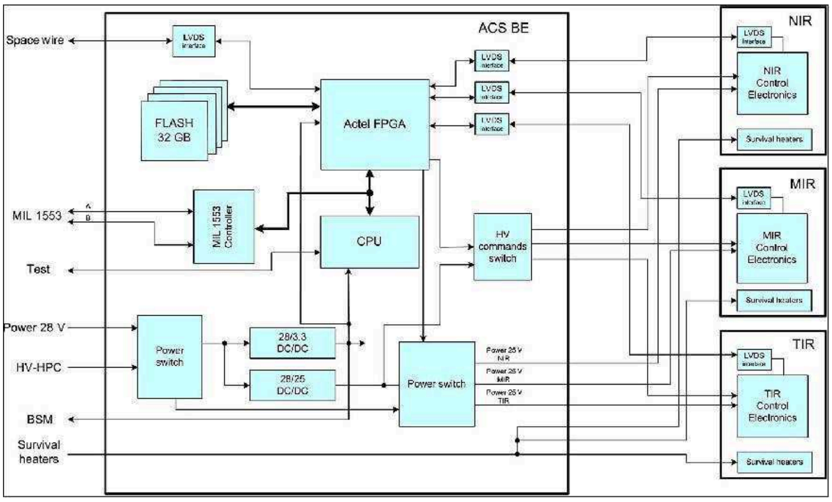

Figure 12: The ACS block diagram. The common electronic block (BE) serves as a single electrical interface of the ACS to the spacecraft in terms of power, commands, and data (image credit: IKI)

General measurement and interface parameters of ACS are summarized in Table 5. ACS consists of four blocks bolted together and sharing a single mechanical interface to the spacecraft. Roughly two-thirds of its mass allocation of 33.5 kg is dedicated to the larger channels, MIR and TIRVIM. The remaining mass is shared between the smaller NIR channel, the BE, the mechanical structure, and the thermal regulation system.

Following the spacecraft requirements, the ACS suite regulates its thermal characteristics, minimizing thermal flux to the spacecraft. The thermal control is provided by several radiators placed at the upper plane of TIRVIM and MIR channels, and a radiator at the right surface of IR (as in Figure 11; +X and -Z axes of the spacecraft, respectively), as well as by independent operational and survival thermal control systems. During the cruise/aerobraking phases of flight, the BE is off and the regulation of survival heaters is provided by dedicated subsystems.

Parameter	NIR	MIR	TIRVIM	ACS
Operation modes	Nadir (dayside and nightside), SO	SO (Solar Occultation)	Nadir (dayside and nightside), SO	Nadir, SO, limb
FOV (Field of View)	2º x 0.02º	10 x 0.5 arcmin	3º full solar disk in SO	
Spectral range	0.73-1.6 µm	2.3-4.3 µm 7 photometers (TBC) 0.2-0.9 µm	2-17 µm, 1.7 µm nadir CH_4	0.25–17 µm full 0.73–17 µm spectral
Instantaneous spectral range	50 x 100 cm^{-1} 16 nm at 1.37 µm	7 x (0.28-0.32 µm) ex. 3.13-3.46 µm	Full range	
Time to measure one spectrum	1 s nadir 50 ms SO	0.5-1 s	4 s nadir 10 s nadir CH_4 2 s SO	
No of spectra/measurement	≤ 10	1 or 2	1 or 2	
Spectral resolution/resolving power	λ/Δλ ≥ 20,000	λ/Δλ ≥ 50,000	1.6 cm nadir 0.2 cm nadir CH_4 0.2 cm SO (λ/Δλ) ~15,000 at 3.3 µm	
Mass (preliminary)	3.3 kg	12.2 kg	11.6 kg	33.5 kg
Power (preliminary)	15 W	30 W	28 W	39–85 W, survival 22 W
Volume	12 x 35 x 25 cm^3	20 x 50 x 60 cm^3	20 x 44 x 30 cm^3	52 x 60 x 47 cm^3
Data rate (preliminary)	0.1 Gbit/day	0.7 Gbit/day	0.7 Gbit/day	1.5 Gbit/day

Table 5: Measurement and interface parameters of the three scientific channels of ACS and the overall values for the whole instrument

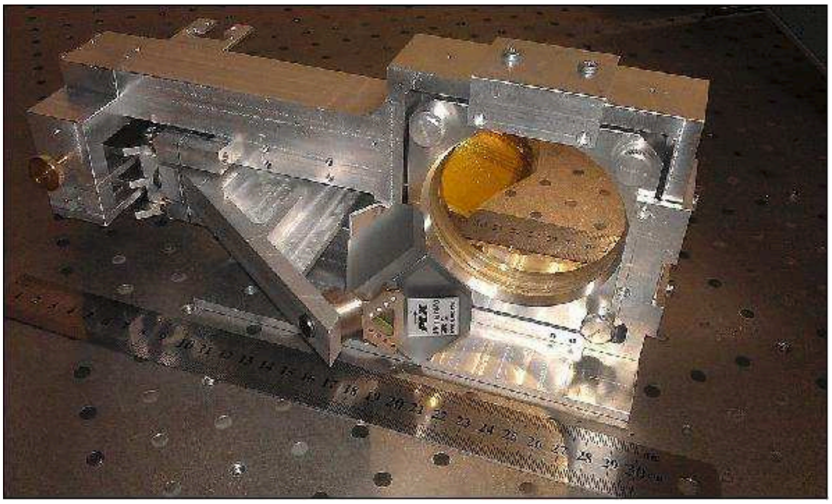

Figure 13: Photograph of the prototype interferometer unit of TIRVIM (image credit: IKI)

• ACS-NIR is an Echelle AOTF (Acousto-Optic Tuneable Filter) spectrometer, which will operate in nadir, limb and solar occultation modes, detecting infrared light in the wavelength range from 0.7 µm - 1.7 µm. [28)]

• ACS-MIR is an Echelle spectrometer, which will operate in solar occultation mode, covering the range from 2.3 µm - 4.6 µm.

• ACS-TIR is a Fourier spectrometer with two channels, one covering 1.7 µm - 17 µm that will operate in nadir and solar occultation modes, and another covering 1.7 µm - 4 µm (optimized for 3.3 µm) that will operate in nadir mode.

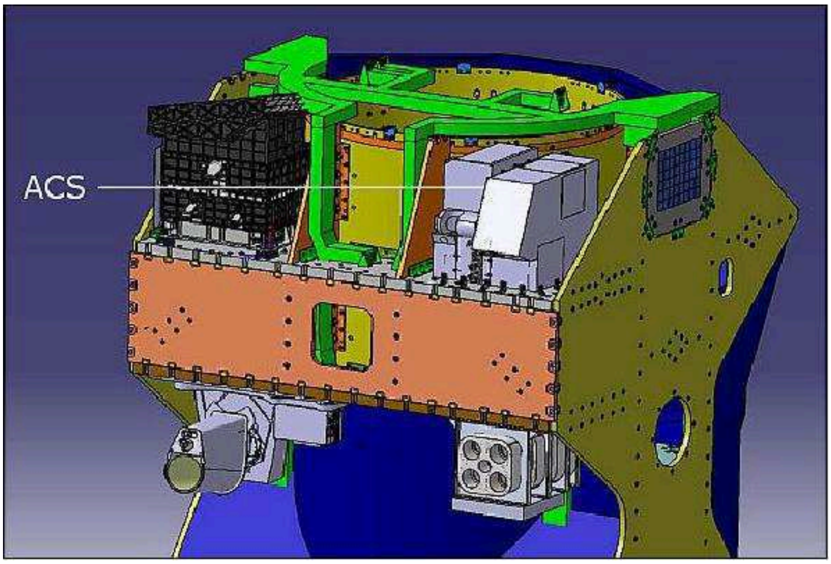

Figure 14: ACS accommodation on the TGO (image credit: ESA)

CaSSIS (Color and Stereo Surface Imaging System)

This high-resolution camera (5 m/pixel) will obtain color and stereo images of the surface covering a wide swath. It will provide the geological and dynamic context for sources of trace gases detected by NOMAD and ACS. PI: Nicolas Thomas, University of Bern, Switzerland. [29)]

CaSSIS will characterize sites that have been identified as potential sources of trace gases and investigate dynamic surface processes – for example, sublimation, erosional processes and volcanism – which may contribute to the atmospheric gas inventory. The instrument will also be used to certify potential landing sites by characterizing local slopes, rocks and other possible hazards.

By acquiring color and stereoscopic images of surface features, CaSSIS will allow scientists to investigate whether specific types of geological processes might be associated with trace gas sources and sinks. The NOMAD and ACS instruments, also being carried by the orbiter, will identify sources of trace gases that could be evidence for biological or geological activity. The CaSSIS imaging system will have a horizontal scale of about five meters per pixel; stereoscopic reconstruction will enable a vertical resolution of about six meters.

CaSSIS will be located on the Mars-surface-facing side of the orbiter. The orbiter science payload will be primarily nadir pointing to keep the Martian surface in constant view. The orbiter will rotate about an axis that will maintain its solar panels oriented towards the Sun while avoiding solar illumination of its thermal radiators. CaSSIS can compensate for the spacecraft's yaw rotation using a drive mechanism, but during nominal stereoscopic imaging the orbiter will pause its yaw-rotation to maximize the paired-image accuracy. The rotation mechanism will be able to turn the entire telescope system by 180º while its support structure remains fixed.

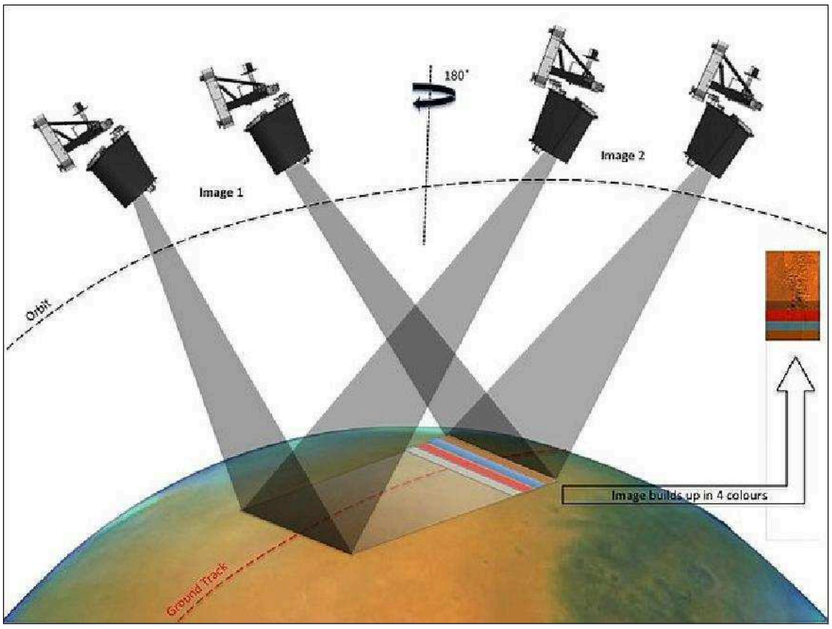

Figure 15: Principle of stereo image acquisition with CaSSIS (image credit: University of Bern)

This rotation system will also enable the camera to acquire stereo images with only one telescope and focal plane assembly. A stereo image pair will be acquired by first rotating the telescope to point 10º ahead of the spacecraft track to acquire the first image, then rotating it 180º to point 10º behind for the second stereo image. Optimal correlation of the stereo signals will be ensured as there will be identical illumination conditions every time a stereo image pair is acquired.

CaSSIS is a high-resolution camera system capable of acquiring color stereo images of surface features possibly associated with trace gas sources and sinks in order to better understand the range of processes that might be related to trace gas emission. The NOMAD and ACS instruments, also being carried by the orbiter, will identify sources of trace gases that could be evidence for biological or geological activity.

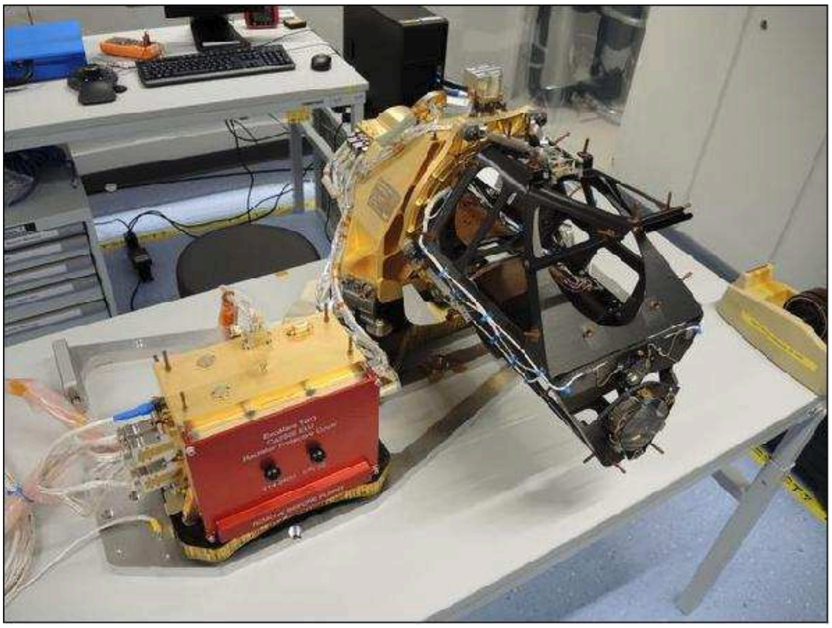
Figure 16: The CaSSIS instrument on a bench in the University of Bern laboratory in Nov. 2015. The electronics unit (left) controls the telescope (right). The black part of the instrument is the telescope structure. The main mirror can be seen in the center. The telescope is cantilevered off the gold colored support structure (image credit: University of Bern)

The camera consists of a three-mirror off-axis telescope with an additional slightly powered folding mirror, which will project an image onto the focal plane. The instrument electronics unit will be mounted separately on the spacecraft deck, next to the telescope. The imager will cover an eight-kilometer-wide swath of the planet's surface in four different wavelength ranges.

Telescope type	TMA (Three-Mirror Anastigmat)
Focal length, aperture, angular scale	880 mm, 135 mm diameter, 5 µrad/pixel
FOV (Field of View)	1.34º x 0.88º
Filter wavelengths (bandwidths)	Pan 650 nm (250 nm) IR 950 nm (150 nm) NIR 850 nm (120 nm) Blue-Green 475 nm (150 nm)

Table 6: CaSSIS imaging characteristics

FREND (Fine Resolution Epithermal Neutron Detector)

This neutron detector will map hydrogen on the surface down to a meter deep, revealing deposits of water-ice near the surface. FREND's mapping of shallow subsurface water-ice will be up to 10 times better than existing measurements. PI: Igor Mitrofanov, Space Research Institute (IKI), Moscow, Russia. [30)]

FREND is a neutron detector with a collimation module that significantly narrows the field of view of the instrument, thus allowing the creation of higher-resolution maps of hydrogen-abundant regions on Mars. FREND will measure the flux of neutrons from the Martian surface; these are produced by the continuous cosmic ray bombardment interacting with the first few meters of rock and regolith. The cosmic rays are sufficiently energetic to break apart atoms in the top 1-2 m of the planetary surface, releasing high-energy neutrons that are then slowed down and absorbed by the nuclei of elements in the surrounding material. Not all the neutrons are captured – many escape, creating a leakage flux of neutrons that the FREND instrument will observe. [31)]

The distribution of neutron velocities, which depends upon how much they were slowed down before escaping, can reveal much about the surface material since it depends on the composition of that material – primarily on its hydrogen content. Even small quantities of hydrogen are known to cause a measurable change in the neutron velocity distribution from the surface of celestial bodies with thin or no atmospheres. This measured hydrogen content can be related to the presence of water.

Epithermal neutrons with energies in the 0.4 eV - 500 keV range will be detected by 3He counters, while neutrons with energies from 0.5 MeV - 10 MeV will be detected using a stylbene scintillator crystal.

FREND also contains a dosimeter module to monitor the local radiation environment. This helps to increase the accuracy of the neutron measurements by providing information about other radiation fluctuations (including space weather driven by the Sun) that can have an impact on the signals from the 3He and stylbene detectors.

FREND is designed to:

• perform high spatial resolution mapping of epithermal and fast neutron fluxes from the Martian surface

• monitor neutrons and charged particle fluxes over broad energy ranges during periods of quiet Sun and during solar particle events

• provide maps of hydrogen concentration in the Martian soil at high spatial resolution

• allow comparison of orbital and ground data as measured by FREND on TGO, the DAN (Dynamic Albedo of Neutrons) instrument on the MSL (Mars Science Laboratory), also known as Curiosity, and the Adron instrument on the ExoMars 2018 Rover

• search for temporal changes in neutron fluxes related to the seasonal Martian water cycle and galactic cosmic ray variations.

FREND builds on previous and current flight heritage, most notably the HEND (High Energy Neutron Detector) on Mars Odyssey; the LEND (Lunar Exploration Neutron Detector) on the LRO (Lunar Reconnaissance Orbiter); the Mercury Gamma and Neutron Spectrometer on BepiColombo; and DAN on MSL.

To map with high spatial resolution the fluxes of neutrons (epithermal, thermal, and fast ones) and, thereafter, hydrogen distribution, FREND is equipped with a set of four ^3He detectors and one stilbene-based scintillation crystal. The ^3He detectors are proportional counters filled with helium-3 under the pressure of 6 atmospheres and placed inside four openings of the collimator. Each of them counts neutrons independently, so that count statistics is higher (and, thus, maps are statistically more reliable) and instrument is more resistant to failures.

These detectors measure neutrons with energies from 0.4 to 500 keV. The scintillation counter, which uses a stilbene crystal, measures fast neutrons with energies 0.5–10 MeV. It is also placed inside the collimator. The scintillation module includes anti-coincidence shielding, to discriminate between signals from high-energy charged particles and neutrons.

FREND's collimation module is a passive element, encasing all five detectors. The collimator consists of two layers, the outer one made of high-density polyethylene, the inner one of enriched boron powder (B_{10}). The neutrons, hitting the collimator's sides, are slowed down by polyethylene, with a large number of hydrogen atoms. So thermalized neutrons then pass through and get into the B_{10} layer, which absorbs them.

The collimator's opening angle narrows the FOV of the detectors to the spot with diameter of 40 km on the Martian surface, when seen from the circular orbit with 400 km altitude, allocated for TGO. Thus, the spatial resolution of the neutron maps of Mars will be enhanced 7.5 times compared to the maps of the HEND instrument.

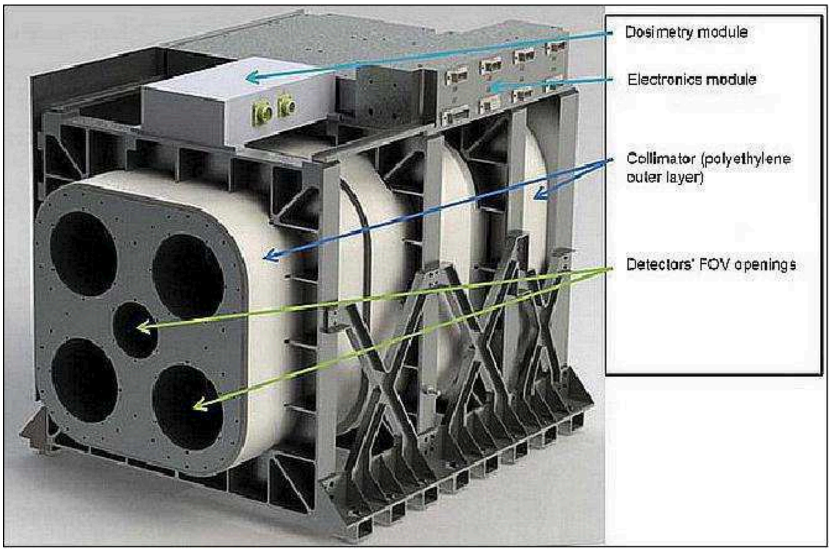

Figure 17: General view of the FREND instrument (image credit: IKI)

The FREND instrument consists of electronics and dosimetry modules (located separately, in the upper part of Figure 17), collimator module (several composite sections), which shield the detectors from radiation coming from outside the nadir direction, and five detectors (not seen in the figure).

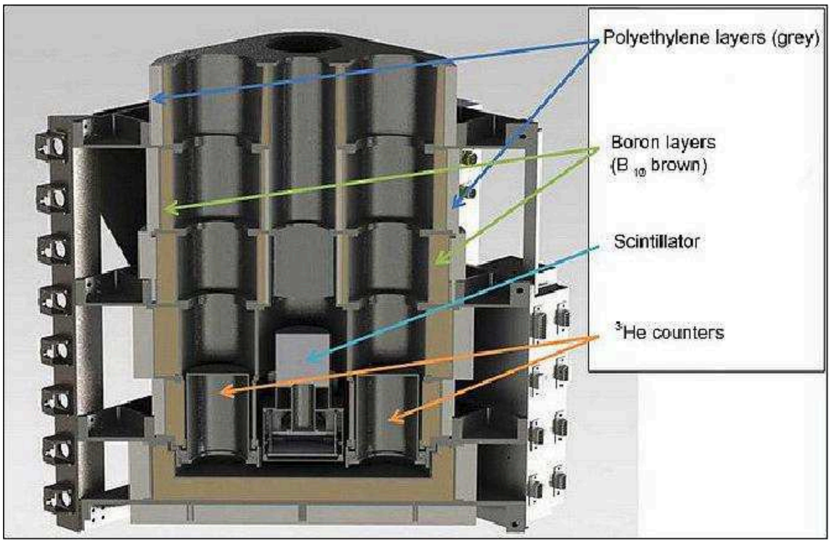

Figure 18: Illustration of the instrument's profile and inner architecture of the collimator and detectors (image credit: IKI)

Mass, power consumption, size	36 kg, 14 W, 465 x 380 x 370 mm
Energy range	0.4–500 keV (neutrons); 0.5–10 MeV (charged particles)
Time resolution	from 1 second
Surface resolution, depth resolution	~40 m, ~ 1 m
Telemetry rate	50 Mbit/day

Table 7: Main parameters of FREND

NOMAD (Nadir and Occultation for Mars Discovery)

NOMAD combines three spectrometers, two infrared and one ultraviolet, to perform high-sensitivity orbital identification of atmospheric components, including methane and many other species, via both solar occultation and direct reflected-light nadir observations. PI: Ann Carine Vandaele, BIRA-IASB (Belgian Institute for Space Aeronomy), Brussels, Belgium. The countries contributing to NOMAD are: Spain, Italy ,United Kingdom, United States of America, Canada. The NOMAD infrared channels were built upon the expertise of BIRA-IASB's successful SOIR (Solar Occultation in the Infra-Red) instrument which is on-board ESA's VEX (Venus Express) mission.

The NOMAD spectrometer suite on the ExoMars Trace Gas Orbiter will map the composition and distribution of Mars' atmospheric trace species in unprecedented detail, fulfilling many of the scientific objectives of the joint ESA-Roscosmos ExoMars Trace Gas Orbiter mission. [32)]

NOMAD is a spectrometer suite that can measure the spectrum of sunlight across a wide range of wavelengths (infrared, ultraviolet and visible). This broad coverage of the instrument enables the detection of the components of the Martian atmosphere, even in low concentrations. In addition to identifying the constituents of the Martian atmosphere, NOMAD will also map their locations. [33)] [34)] [35)] [36)]

The measurements will be carried out in solar occultation, i.e. the instrument points toward the Sun when the Orbiter moves at the dark side of Mars, as well as in nadir mode, i.e. looking directly at the sunlight reflected from the surface and atmosphere of Mars. The inclination of the Orbiter has been chosen to optimize the science that can be done with the instrument suite.

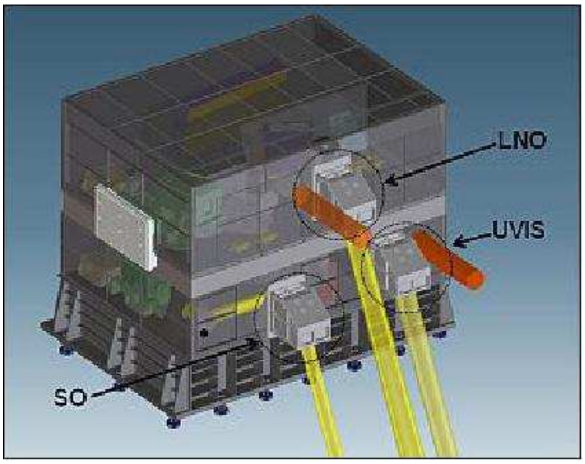

Figure 19: Illustration of the NOMAD instrument (image credit: BIRA)

NOMAD covers the infrared (2.2-4.3 µm) and the ultraviolet-visible (0.2-0.65 µm) spectral regions, using the following three operational modes:

• **SO** (Solar Occultation) mode: The SO operates by observing up to six small slices of the full spectral range each second. This allows observing several different target molecules that absorb at different wavelengths, whilst maximizing the SNR (Signal-to-Noise Ratio) for each. During a solar occultation, which lasts about 5 minutes, 300 spectra at each wavelength can be taken providing a profile of the atmospheric composition from the top of the atmosphere down to almost the surface, depending on dust levels.

• **LNO** (Limb, Nadir and Occultation) mode: The LNO is sensitive to the lower light levels during nadir observations on Mars. The nadir coverage will facilitate the study of the atmospheric composition in addition to examining Martian surface features, such as ice and frost. This measurement will be carried out on average every 3 to 4 sols (a solar day on Mars, or sol, is 24 hours and 39 minutes) with varying local times across the planet.

• **UVIS** (Ultraviolet and Visible) mode: The UVIS will image the wavelength domain between 200 and 650 nm, every second, covering and providing more information about several interesting molecules, such as ozone, sulphuric acid and aerosols in the atmosphere.

The SO spectrometer channel will perform occultation measurements, operating between 2.2 and 4.3 µm at a resolution of ~0.15 cm^{-1}, with 180 to 1000 m vertical spatial sampling. LNO will perform limb scanning, nadir and occultation measurements, operating between 2.2 and 3.8 µm at a resolution of ~0.3 cm^{-1}. In nadir, global coverage will extend between ± 74º latitude with an IFOV (Instantaneous Field of View) of 0.5 x 17 km on the surface. This channel can also make occultation measurements should the SO channel fail. UVIS will make limb, nadir and occultation measurements between 200 and 650 nm, at a resolution of 1.5 nm. It will achieve 300 m vertical sampling with a 1 km vertical resolution during occultation and 5 x 60 km ground resolution during 15 s nadir observations (IFOV of 5 x 5 km).

An order-of-magnitude increase in spectral resolution over previous instruments will allow NOMAD to map previously unresolvable gas species, such as important trace gases and isotopes. CO, CO_2, H_2O, C_2H_2, C_2H_4, C_2H_6, H_2CO, CH_4 SO_2, H_2S, HCl, O_3 and several isotopologues of methane and water will be detectable, providing crucial measurements of the Martian D/H ratios. It will also be possible to map the sources and sinks of these gases, such as regions of surface volcanism/outgassing and atmospheric production, over the course of an entire Martian year, to further constrain atmospheric dynamics and climatology. NOMAD will also continue to monitor the Martian water, carbon, ozone and dust cycles, extending existing data sets made by successive space missions in the past decades, from which surface UV radiation levels will be determined. Using SO and LNO in combination with UVIS, aerosol properties such as optical depth, composition and size distribution can be derived for atmospheric particles and for distinguishing dust from ice aerosols, as demonstrated on Venus by the analysis of the SPICAV-UV, IR and SOIR data.

Wavelength λ, Wavenumber	2.3-4.3 µm, 4250–2320 cm^{-1}
Instrument line profile (ILP), ILP for CH_4	0.22 cm^{-1}, 0.15 cm^{-1}
Pixel sampling FWHM (Full Width Half Maximum)	≥2
Polarization	linear, parallel to slit
Resolving power λ/Δλ	20,000
Slit width in object space, Slit length in object space	2 arcmin, 30 arcmin
FOV (Field of View)	2 x 30 arcmin
Spatial sampling, vertical sampling	1 arcmin, ≤1 km
SNR	≥900
Mass ((including all NOMAD electronics)	13.5 kg
Dimensions (without periscope)	490.5 x 353 x 208 mm^3

Table 8: Summary of SO channel specifications

General	

Wavelength λ, Wavenumber	2.3-3.8 µm, 4250–2630 cm^{-1}
Instrument line profile (ILP)	0.5 cm^{-1}
Pixel sampling FWHM (Full Width Half Maximum)	≥2
Polarization	linear, parallel to slit
Resolving power λ/Δλ	10,000
Slit width in object space, Slit length in object space	4 arcmin, 150 arcmin
FOV (Field of View)	4 x 150 arcmin
Spatial sampling	1 arcmin
Entrance aperture diameter	29.5 x 24 mm^2
Mass	9.4 kg
Dimensions (without periscope)	445 x 327 x 182 mm^3
SO (Solar Occultation)	
Vertical sampling, SNR	≤1 km, ≥900
Nadir footprint (400 km orbit)	60 x 0.3 $arcmin^2$
SNR, SNR for CH_4	≥400, ≥1000

Table 9: Summary of LNO channel specifications

Parameter	SO (Solar Occultation)	Nadir Observation
Volume, mass	128 mm x 152 mm x 89 mm, 950 g	
Spectral range, spectral resolution	200-650 nm, 1.5 nm	
Numerical aperture of the fiber	0.22	
F-number	2.15	2.18
FOV, IFOV	2 arcmin, 1 km	43 arcmin, 5 km x 5 km
Typical observation binning, observation time	8 rows, 0.2 s	64 rows, 15 s
Footprint of nadir channel during a typical 15 s observation		60 km x 5 km
Vertical sampling	< 300 m (Δz at limb)	
SNR (specification requirement)	230-450 nm: SNR≥1000 450-650 nm: SNR≥500	230-450 nm: SNR≥500 450-650 nm: SNR≥250
Detector e2V back-thinned CCD30-11 Pixel pitch Dark current at 293 K Dark signal non uniformity on binned column of 256 pixels at 293 K Read-out noise Detector full well capacity (at 293 K)	2D 1024 x 256 pixel CCD 26 µm 1000 $e^{-/pixel/s}$ 30 $e^{-/pixel/s}$ 6 $e^{-/pixel}$ 540 000 e^-	

Table 10: NOMAD-UVIS characteristics and performances

The mass of NOMAD is 28.86 kg including margins. From this, the SO and LNO optical bench masses are 13.35 kg (including all NOMAD electronics) respective 9.4 kg. The remaining mass is attributed to UVIS (940 g) and harnessing, MLI (Multilayer Insulation), and instrument-to-spacecraft mounting hardware (3.7 kg).

Sensor complement of Schiaparelli (DREAMS, AMELIA, COMARS+, INRRI, DECA)

Science investigations to be carried on Schiaparelli, the ExoMars entry, descent and landing demonstration module (EDM), were selected in June 2011 following an announcement of opportunity released by ESA and NASA. [37]

The selected investigations consist of a surface payload, called DREAMS, which will operate on the surface of Mars for 2–8 sols, and an investigation known as AMELIA, for entry and descent science investigations using the spacecraft engineering sensors.

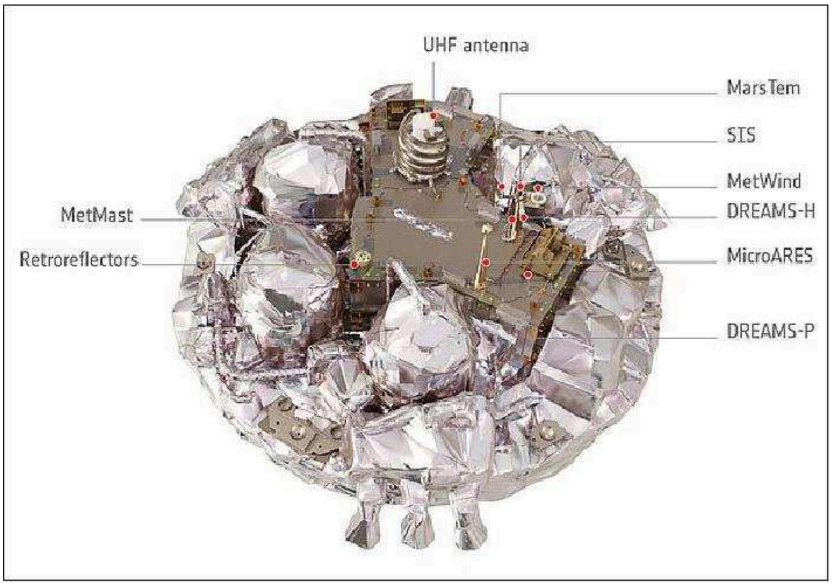

Figure 20: Artist's rendition of the Schiaparelli EDM without heat shield and back cover (image credit: ESA, ATG medialab) [38)]

DREAMS (Dust Characterization, Risk Assessment, and Environment Analyzer on the Martian Surface)

The surface payload, consisting of a suite of sensors to measure local wind speed and direction (MetWind), humidity (DREAMS-H), pressure (DREAMS-P), atmospheric temperature close to the surface (MarsTem), transparency of the atmosphere (Solar Irradiance Sensor, SIS), and atmospheric electric fields (Atmospheric Radiation and Electricity Sensor, MicroARES). PI: Francesca Esposito, INAF – Osservatorio Astronomico di Capodimonte, Naples, Italy; Co-PI: Stefano Debei, CISAS –Università di Padova, Italy.

DREAMS will provide the first measurements of electric fields on the surface of Mars (with MicroARES). Combined with measurements (from SIS) of the concentration of atmospheric dust, DREAMS will provide new insights into the role of electric forces on dust lifting, the mechanism that initiates dust storms.

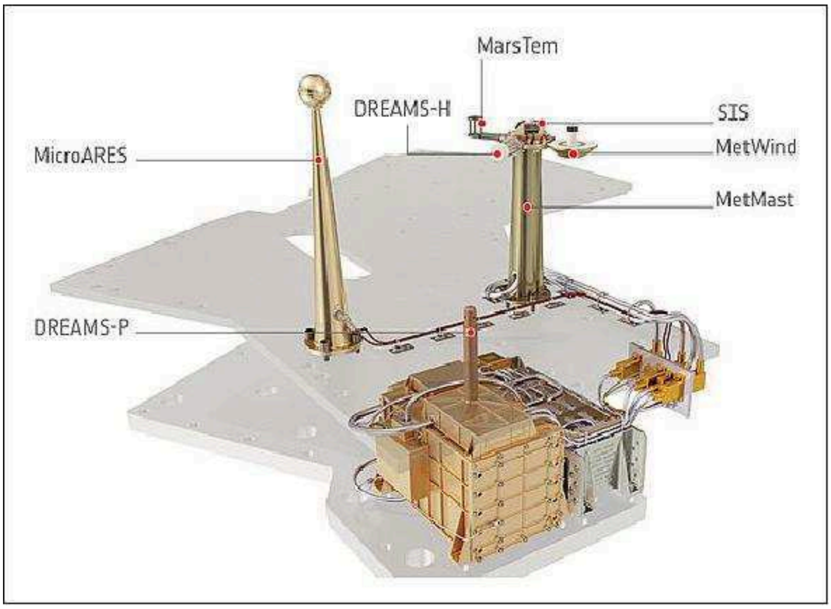

Figure 21: Artist's rendition of DREAMS (image credit: ESA, ATG medialab) [39)]

AMELIA (Atmospheric Mars Entry and Landing Investigation and Analysis)

The objective of AMELIA is to collect entry and descent science data using the spacecraft engineering sensors. PI: Francesca Ferri, Università degli Studi di Padova, Italy. The engineering data is used to reconstruct Schipiarelli's trajectory and determine atmospheric conditions, such as density and wind, from a high altitude to the surface. These measurements are key to improving models of the Martian atmosphere.

COMARS+ (Combined Aerothermal and Radiometer Sensors instrumentation package)

The objective of COMARS+ is to measure aerothermal parameters on the exterior of Schiaparelli as it passes through the atmosphere. Team leader: Ali Gülhan, DLR, Cologne, Germany. Determining what happens to Schiaparelli's external surface as it penetrates the Martian atmosphere and descends to the surface is essential in order to understand the engineering and physics required to make entry, descent, and landing on Mars a success. COMARS+, which is installed on the back cover of Schiaparelli will gather the data to study this.

COMARS+ consists of three combined sensors (COMARS) spaced equally across the back cover of Schiaparelli, one broadband radiometer, and an electronic box (inside the module). The entire package has a mass of 1.73 kg and draws 4.5 W of power. The sensors, located on the back cover of the module, will measure the pressure, the temperature of the module's surface, the rate at which heat energy is transferred to the surface (total heat flux rate), and the amount of radiated heat from the hot gas to the back cover (radiative heat flux).

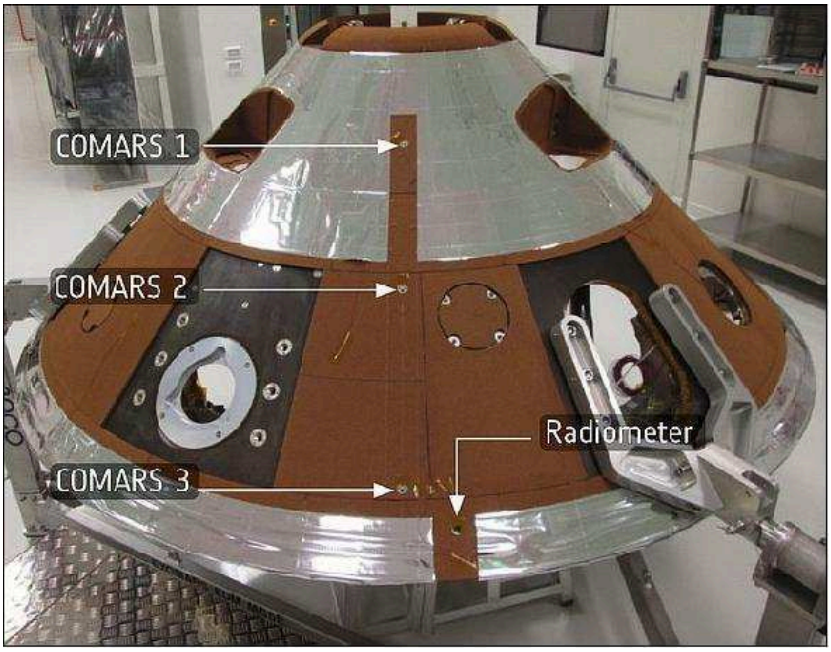

Figure 22: COMARS+ sensors on Schiaparelli (image credit: DLR) [40]

Two so-called ICOTOM narrow band radiometers in each COMARS sensor are provided by CNES. In addition, a broadband radiometer provided by DLR is integrated close to the COMARS 3 sensor. The data produced from this instrument package will provide essential input for the improved design of future missions landing on Mars. The COMARS+ package is provided by the German Aerospace Center (DLR).

INRRI (INstrument for landing-Roving laser Retroreflector Investigations)

The INRRI instrument is developed by ASI together with INFN (Italian National Institute for Nuclear Physics). Team leader: Simone Dell'Agnello, INFN/LNF National Laboratories of Frascati), Frascati, Italy. INRRI will be the first passive laser reflector on the surface of Mars and the first to go further than the Moon. [41]

INRRI for Mars Rovers is a new enabling technology for planetary exploration because: it will provide accurate Rover georeferencing during its exploration activity, recording its positions where significant geological measurements have been made by Rover instruments as reference for future exploratory missions. Example of the latter: future sample return mission targeting an INRRI-georeferenced position explored/surveyed by the Rover of particularly high interest to NASA/ESA/ASI long-term goals for Mars exploration (outstanding astrobiologically relevant sites, potential biosignature locations). [42]

INRRI is a laser retroreflector micropayload of about 50 gr weight and about 55 mm x 20 mm size. It will be laser tracked by Mars orbiters capable of laser ranging and/or laser altimetry, like for example LOLA (Lunar Orbiter Laser Altimeter) on LRO (Lunar Reconnaissance Orbiter) and/or laser communication, like for example LLCD (Lunar Laser Comm demo) on LADEE (Lunar Atmosphere and Dust Environment Explorer), or OPALS (Optical PAyload for Lasercomm Science) on the ISS.

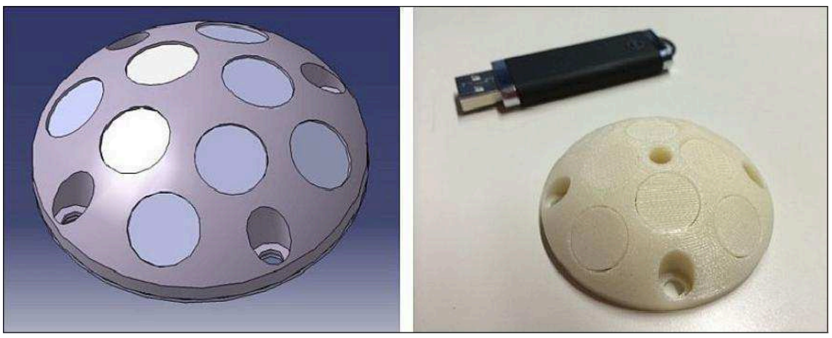

Figure 23: Drawing and photo of INRRI (Instruments for landing/Roving laser Retroreflector Investigations), image credit: INFN/LNF

INRRI for Mars Rovers is a new, wavelength-independent, enabling technology to test, validate, and locally diagnose, on Mars, certain aspects related to transmitter and receiver subsystems for future laser-communication from Mars orbiters to Earth, an activity that is a long-term interest for future Mars missions. This will be also applied to future laser-comm between Mars orbiters and Mars surface (future Rovers and distributed installations).

DECA (Descent Camera)

Will record several images during descent, but will not be able to take any images of the surface after landing. Team leader: Detlef Koschny, ESA Science Support Office. [43)]

DECA is the flight spare of the VMC (Visual Monitoring Camera), which flew on the Herschel spacecraft. It will be used to perform high-resolution imaging of the Schiaparelli landing site, to determine the transparency of the martian atmosphere, and to support the generation of a 3-D topography model of the surface of the landing region.

DECA was designed and built by OIP (Optique et Instruments de Précision) in Belgium for ESA.The camera has a mass of 0.6 kg and dimensions of about 9 cm x 9 cm x 9 cm.

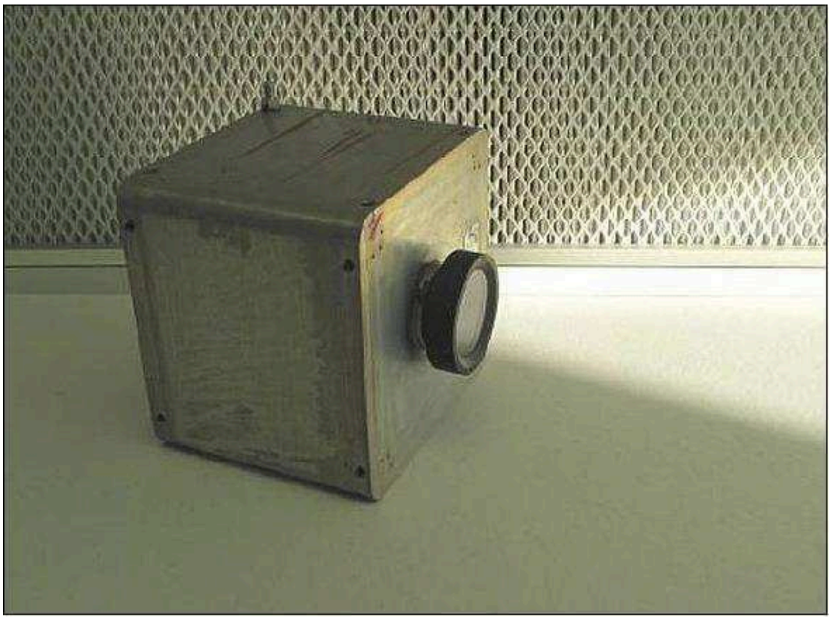

Figure 24: Photo of DECA (Descent Camera) on Schiaparelli (image credit: ESA)

DECA will start taking images after the front-shield of Schiaparelli has been jettisoned during the journey through the martian atmosphere to the planet's surface. It will take 15 images at 1.5 s intervals. These images will be stored in local memory. To avoid electrostatic discharges affecting the instrument, there will be a delay of several minutes after Schiaparelli has landed on the surface of Mars, before the data are read out by Schiaparelli's computer and subsequently downlinked to Earth.

Arriving at Mars

Although designed to demonstrate entry, descent and landing technologies, Schiaparelli also offers limited, but useful, science capabilities. It will deliver a science package that will operate on the surface of Mars for a short duration after landing, planned to last approximately 2-4 sols (martian days). [44)]

• Three days before reaching the atmosphere of Mars, Schiaparelli will separate from the Orbiter.

• The module will then coast to Mars during which phase it will remain in hibernation mode in order to reduce its power consumption.

• Schiaparelli will be activated a few hours before entering the atmosphere of Mars, at an altitude of 122.5 km and a speed of approximately 21,000 km/h.

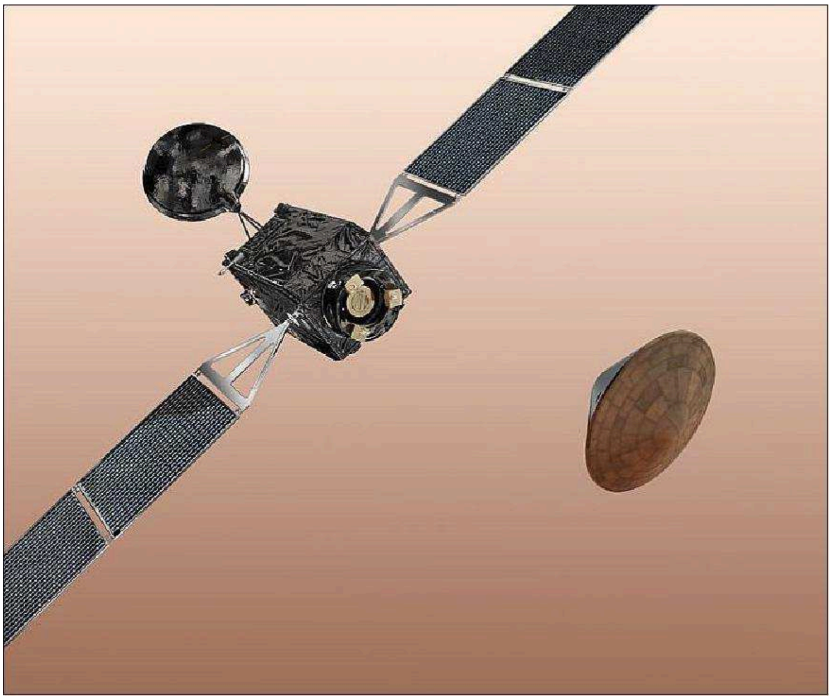

Figure 25: Artist's rendition showing the Schiaparelli Rover release from the TGO (Trace Gas Orbiter) for a landing on the surface of Mars (image credit: ESA)

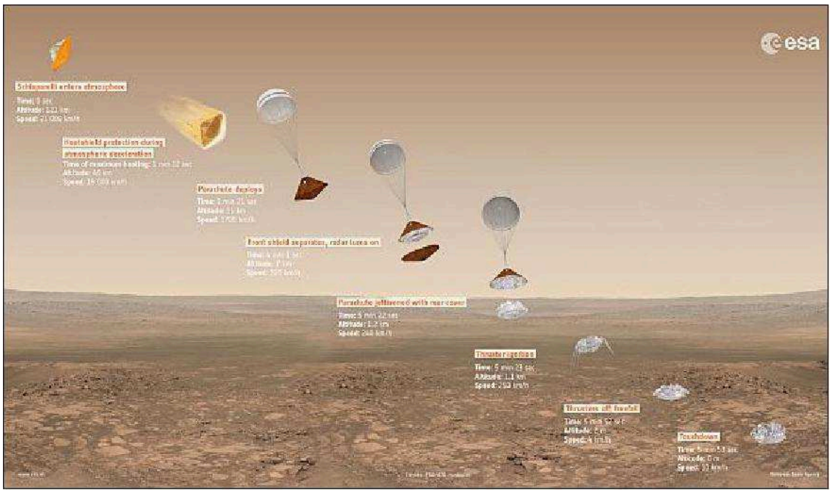

Figure 26: Schiaparelli descent sequence (image credit: ESA, ATG medialab)

• Entry: An aerodynamic heatshield will protect Schiaparelli from the severe heat flux and deceleration, so that at an altitude of about 11 km, when the parachute is deployed, it will be travelling at around 1650 km/h.

• Descent: The module will first release the front heatshield and then the rear heatshield will also be jettisoned.

- Schiaparelli will turn on its Doppler radar altimeter and velocimeter to locate its position with respect to the Martian surface.

• Landing: The liquid propulsion system will be activated to reduce the speed to less than 7 km/h when it is 2m above the ground. At that moment the engines will the switched off and the lander will drop to the ground.

- As Schiaparelli lands, the final shock will be cushioned by a crushable structure built into module.

- The primary landing site has been identified: it is a plain known as Meridiani Planum, a plain located 2 degrees south of Mars' equator in the westernmost portion of Terra Meridiani. This area interests scientists because it contains an ancient layer of hematite, an iron oxide that, on Earth, almost always forms in an environment containing liquid water.

A communication link between Schiaparelli and the TGO (Trace Gas Orbiter) will facilitate the realtime transmission of the most important data measured by the module. The complete set of data acquired will be transmitted to the Orbiter within 8 sols after the landing (a solar day on Mars, or sol, is 24 hours and 37 minutes). The Schiaparelli mission then comes to an end.

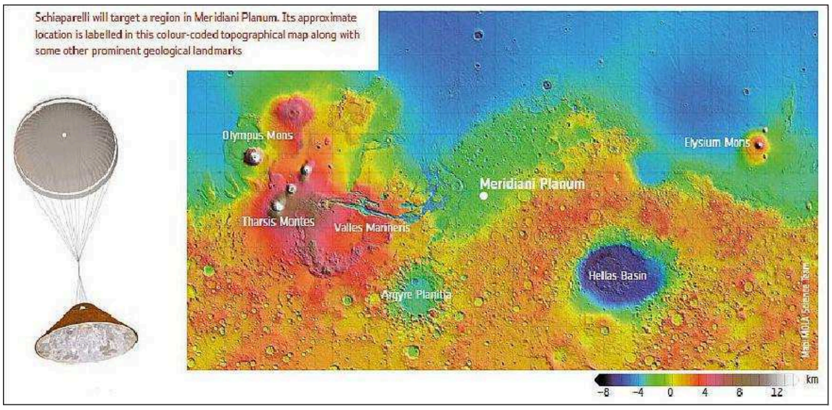

Figure 27: Illustration of Schiaparelli's landing site, acquired by the Mars Reconnaissance Orbiter (image credit: NASA/JPL, Arizona State University, ESA, Ref. 5)

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The information compiled and edited in this article was provided by Herbert J. Kramer from his documentation of: "Observation of the Earth and Its Environment: Survey of Missions and Sensors" (Springer Verlag) as well as many other sources after the publication of the 4th edition in 2002. - Comments and corrections to this article are always welcome for further updates (herb.kramer@gmx.net).

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