PRODEX EXPERIMENT ARRANGEMENT CHANGE NOTICE
Institute: Institute of Atmospheric Physics (IAP) Prague
PEA No: 4000117599 CN No: 5 Supplier Code:1000002304
Contract: MAIGRET-WAM

Title of area affected: Funds	Article(s) of the Arrangement: 2 Initiator of change: IAP

Description of change

- Reshuffling of funds between cost cathegories and years (2019 – 2022)
- Transfer of 13 530 EUR from the budget allocated for direct purchases by PRODEX to institute costs

Reason for change

- More high reliability components, material and mechanical parts had to be procured in 2019 to secure the manufacturing of WAM sensor and electronics.
- Covid-related restrictions limit international travel after 2020
- Additional personnel costs in 2021/2022 are required as a consequence of non-conformances discovered during the AIT activities.

Funds in addition to those stipulated in Article 2.1:
13 530 EUR

Effect on other Arrangement provisions N/A	Commencement of Term 01-12-2015 End of Term 31-12-2022

Institute

Institute's representative(s): Dr. Radan Huth, director	Date 17.2.2022

ESA

PRODEX Office representative: Jens Loehring Veronique Dowson Michel Lazerges	Date 16.2.2022

Appendix 1

Work Description

Overall Objective (mission):

The ExoMars Programme consists of two missions to Mars which are planned to be launched in 2016 and 2022. The launch of the latter mission is planned for August-October 2022 from Baikonur on Proton M. The anticipated arrival to Mars will be in 2023. The landing is planned by a direct entry from a hyperbolic trajectory, after the dust storm season. The landing site is still to be defined, but must be safe for landing and appropriate for "search for life" science. Anticipated latitudes are between 5º S and 25º N, all longitudes.

The mission will land a Rover, provided by the European Space Agency (ESA), making use of a 2000-kg Descent Module (DM) contributed by the Russian federal space agency (Roscosmos). The DM will travel to Mars on an ESA-provided Carrier Module (CM). 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 Radioisotope Heating Units (RHUs). The Rover will also include a 2-m drill for subsurface sampling and a Sample Preparation and Distribution System (SPDS), supporting the suite of geology and life seeking experiments in the Rover's Analytical Laboratory Drawer (ALD). The Russian Surface Platform (SP) will contain a suite of instruments which will be mainly concentrated on environmental and geophysical investigations. Within Roscosmos, ExoMars is part of the Russian federal space programme and is supported by the Russian Academy of Sciences.

The ExoMars programme's scientific objectives are:

1. To search for signs of past and present life on Mars;
2. To investigate the water/geochemical environment as a function of depth in the shallow subsurface;
3. To study martian atmospheric trace gases and their sources;
4. To characterise the surface environment.

The ExoMars Surface Platform will conduct environmental and geophysical measurements in support of objective 4. After the Rover is released, the ExoMars Surface Platform will begin its science mission to study the surface and subsurface environment at the landing location. Data relay function will be provided by the Trace Gas Orbiter (TGO) launched as a part of the 2016 ExoMars mission. Whereas the Rover with the Pasteur payload (mass 310 kg, including drill/SPDS and instruments) is designed for a lifetime of 220 sols, the surface platform has anticipated lifetime of 1 Martian year (~670 sols), (ExoMars Science Management Plan, v6).

The proposed Surface Platform instruments are defined in the ExoMars Surface Platform Experiment Proposal Information Package (EXM-SP-EPIP-IKI-0001) of 31 March 2015. This package defines technical, managerial and programmatic data relevant in the context of the Announcement of Opportunity (AO) for European payload elements on the Surface Platform (SP) of the ExoMars mission. SP has anticipated lifetime of one terrestrial year according to this document. The SP science payload development is the responsibility of Roscosmos, with the exception of the contributions selected through this call.

Roscosmos has named the Space Research Institute of Russian Academy of Sciences (IKI) to be the leading entity for the development of the SP scientific payload, with the exception of the contributions selected through this call. IKI will manage the development of the SP payload according to Russian standards. The following European contributions to Russian-led instruments are envisaged:

1. Instrument: METEO

- Humidity sensor
- Pressure sensor
- Optical depth sensor
- Solar irradiance sensor
- Magnetometer
- Dust sensor

Contact : [redacted]

2. Instrument: FAST
- Interferometer unit

Contact: [redacted]

3. Instrument: M-DLS
- Spectroscopic support, procurement and characterisation of diode lasers, principal optical, vacuum, electronic parts and modules, laboratory M-DLS prototype characterisation, development of the inversion algorithms

Contact: [redacted]

4. Instrument: Dust Suite
- Aerosol particle counter
- Electric field sensor

Contact: [redacted]

5. Instrument: MGAP
- Mass spectrometer

Contact: [redacted]

6. Instrument: MAIGRET
- Wave analyser module

Contact: [redacted]

The Wave analyser module which is the subject of this PRODEX proposal is a part of the MAIGRET (MArtIan GRound Electromagnetic Tool) instrument. Its development would be based on our previous cooperation with IKI in the frame of the Resonance and Luna-Resource-Orbiter spacecraft projects, where we work on similar hardware contributions.

The module will be dedicated for the measurement of magnetic-field fluctuations in the frequency band from 100 Hz to 20 kHz. The main scientific targets of the Wave analyser module are:

a) electromagnetic emissions of atmospheric origin: dust storms, wave activity originated in electrical discharges;
b) ionosphere and atmosphere-lithosphere interactions on Mars related to space weather effects;
c) magnetic anomalies on the surface of the planet;
d) internal structure of the planet using electromagnetic sounding methods based on the analysis of the response of deep conductive structures to excitation by time-varying external electromagnetic field of natural origin.

Role of the Institute:

The Institute of Atmospheric Physics (IAP) of the Czech Academy of Science is proposing to develop, build, test, and operate the Wave analyzer module for the MAIGRET instrument [redacted], as a part of the European payload element on the Surface Platform of the ExoMars 2020 mission, with

[redacted] having the role of Co-Principal Investigator of the MAIGRET instrument with the overall responsibility for the Wave analyzer module.

Project term (to be) covered by the PRODEX Experiment Arrangement:

Phases B-D, definition and implementation: 2015 – 2022

Further phases:

- launch in September 2022,
- cruise phase: 2022-2023,
- nominal operations: 2023-2025,
- data reduction, submission of data products to the planetary science archives: 2023-2026.

Brief description of Main Tasks:

The Wave analyzer module for the MAIGRET instrument will measure magnetic-field and electric-field fluctuations in the frequency band from 100 Hz to 20 kHz and electric field fluctuations up to 8 MHz. The design of the module will correspond to its scientific goals and technical limitations of the instrument. The module will measure both overview spectra and short waveform packets.

The design will be largely based on heritage from the Resonance ELMAVAN instrument, Luna-Resource-Orbiter LEMRA-L instrument, TDS subsystem of the Solar Orbiter RPW instrument, IME-HF analyzer for the TARANIS mission of CNES, and the JUICE RPWI- LFR subsystem, in order to save the development time in the very tight project schedule. This is a very important aspect of the project.

The Wave analyser module will perform digitization and onboard processing of the signal from the sensor assembly composed of a horizontal magnetic field search coil, a deployable vertical electric field antenna, preamplifiers and deployment electronics. The signal will be processed by integrated digital logic implemented in an FPGA, performing filtering, decimation and spectral analysis of the signals. This science-based on-board processing allows us to save spacecraft telemetry and increase coverage by high quality pre-processed scientific data products. The device will contain analog circuits for input signal conditioning, as well as digital data processing and communication circuits. The search coil and electric antenna signals will first pass through anti-aliasing low pass filters. Further processing improves dynamic range and produces 16-bit digital data. All digital processing is done in an FPGA. Tasks include ADC control and data acquisition, input CIC and/or FIR digital filters with decimation, FFT and power spectrum calculation, data buffering, and communication with the S/C data acquisition and control subsystems (telecommand processing, telemetry packet preparation and transmission).

The wave analyser will use a part of the 1 kByte/s digital bandwidth of the MAIGRET instrument to generate compressed data products related to its scientific goals, including the results of the onboard spectral analysis of the search coil and electric antenna signals and waveform snapshots. The components, materials and processes will be also compliant with the temperature range limits of the MAIGRET instrument, leading to operational temperatures from –20 °C to +50 °C and storage temperatures from –50 °C to +50 °C. The mass and power consumption limits of the MAIGRET instrument (1.7 kg and 5W, respectively) will be taken into account in the analyser and sensor assembly design. The electronics board of the analyser will be placed in the MAIGRET box which will be powered by a separate power supply system of the platform in order to increase the reliability of the instrument. The sensor assembly (a horizontal magnetic field search coil, a deployable vertical electric field antenna, preamplifiers and deployment electronics) will be attached to the outer edge of one of the solar panels.

The EXOMARS surface platform is assigned COSPAR planetary protection category IVa, as it is not supposed to carry instruments for the investigations of extant Martian life. Reflecting the category IVa requirements, the bioburden of the Wave analyzer module shall be $\leq 3x10^5$ bacterial spores and the average bioburden of the Wave analyzer module shall be ≤ 300 bacterial spores/m^2 on exposed internal and external surfaces.

The Wave analyzer module will be compatible with Dry Heat Microbial Reduction (DHMR), alcohol cleaning (IPA or ethanol) and with damp swab assays as per assay procedure described in ECSS-Q-ST-70-55C (Microbial examination of flight hardware and cleanrooms). Parts qualifications and manufacturing processes when selecting components will be considered with respect to planetary protection requirements as described in ECSS-Q-ST-70-53C (Materials and hardware compatibility tests for sterilization processes). The flight hardware will be assembled and tested in ISO 7 clean room conditions and transported in an appropriate transport container. The bioburden on the Wave analyzer module at delivery on exposed internal and external surfaces will be assessed and documented. The bio burden monitoring procedures will respect the contamination predictions budgets. Corrective actions in terms of design, shielding and purging in case the predictions are outside acceptance limits will be defined.

Cleanliness and contamination control is an integral part of planetary protection tasks as the DHMR treatment could be a potential source of molecular and particular organic contamination. Firstly, the dead bioburden is not removed by DHMR and secondly the exposure to high temperatures might produce contaminants by outgassing. Parts qualifications and manufacturing processes when selecting components will be considered with respect to cleanliness and contamination control requirements as described ECSS-Q-ST-70-01C (Cleanliness and contamination control). The materials will be selected according to the outgassing criteria using the ESA outgassing database. (http://esmat.esa.int/Services/outgassing_data/outgassing_data.html).The flight hardware will be assembled and tested in ISO 7 clean room conditions and transported in an appropriate transport container.

IAP will be responsible as a Co-Principal Investigator institute for the development of the proposed Wave analyzer module for the MAIGRET instrument, as a part of the European payload element on the Surface Platform of the ExoMars mission, taking responsibility for project management, interface with ESA and IKI, reviews and documentation. In the frame of the Wave analyzer module for the MAIGRET instrument IAP will be also responsible for the development and delivery of all subsystems (all required models), consisting of sensor assemblies, electronics boards, FPGA firmware and Ground Support Equipment. IAP has experience of building successful VLF receivers beginning with five MAGION missions. More recently, receivers with digital onboard processing have been developed for the Resonance, Luna-Resource-Orbiter, and Solar Orbiter missions. IAP has also developed an HF receiver for the upcoming TARANIS mission and is developing an LF receiver subsystem of the RPWI instrument for the JUICE mission.

Overview of the work breakdown:

1. Project management
    - Tasks related to the PI role of the Wave analyzer module and Co-PI role of the MAGRET instrument
    - Management of the interface with ESA and IKI
    - Planetary protection tasks
    - Input to reviews and documentation

2. The main board of the Wave analyzer module for the MAIGRET instrument.

a) Development and design of algorithms for science-based onboard processing

- Research of electromagnetic emissions of atmospheric origin
- Research of time-varying electromagnetic plasma waves of natural origin
- Implementation of algorithms for science-based onboard processing

b) Thermal, mechanical, and electronics design

- Design contribution to the MAIGRET Structural Model (SM) and to the MAIGRET Thermal Model (TM)
- Mechanical, and electronics design of the Instrument Electrical Interface Simulator (EIS) of the main board of the Wave analyzer module for the MAIGRET instrument.
- Thermal, mechanical, and electronics design of the EQM of the main board of the Wave analyzer module for the MAIGRET instrument.
- Update of the thermal, mechanical, and electronics design for the Flight Model (FM) and Flight Spare Model (FSM) of the main board of the Wave analyzer module for the MAIGRET instrument.

c) FPGA and software design

- FPGA and software design of the Instrument Electrical Interface Simulator (EIS)of the Wave analyzer module for the MAIGRET instrument.
- FPGA and software design of the EQM board of the Wave analyzer module for the MAIGRET instrument.
- Update of the FPGA and software design for the Flight Model (FM) and Flight Spare Model (FSM) of the Wave analyzer module for the MAIGRET instrument.

d) Assembly/manufacturing

- Manufacturing and assembly of the Instrument Electrical Interface Simulator (EIS)of the Wave analyzer module for the MAIGRET instrument (main board, delivered to IKI)
- Manufacturing and assembly of the EQM main board which will stay at IAP for future testing and analysis purposes
- Manufacturing and assembly of the Flight Model (FM) of the main board of the Wave analyzer module for the MAIGRET instrument (delivered to IKI).
- Manufacturing and assembly of the Flight Spare Model (FSM) of the main board of the Wave analyzer module for the MAIGRET instrument (delivered to IKI).

e) Testing activities

- EGSE development
- Functional testing of the Instrument Electrical Interface Simulator (EIS) of the Wave analyzer module for the MAIGRET instrument (delivered to IKI).
- Functional, thermal vacuum, and vibrational testing of the EQM main board.
- Functional, thermal vacuum, and vibrational testing, as well as the cleanliness and contamination control of the Flight Model (FM) of the main board of the Wave analyzer module for the MAIGRET instrument
- Functional, thermal vacuum, and vibrational testing, as well as the cleanliness and contamination control of the Flight Spare Model (FSM) of the main board of the Wave

analyzer module for the MAIGRET instrument.

3. The sensor assembly of the Wave analyzer module for the MAIGRET instrument.

a) Thermal, mechanical, and electronics design

- Thermal, mechanical, and electronics design of the EQM of the sensor assembly of the Wave analyzer module for the MAIGRET instrument.
- Update of the thermal, mechanical, and electronics design for the Flight Model (FM) and Flight Spare Model (FSM) of the sensor assembly of the Wave analyzer module for the MAIGRET instrument.

b) Assembly/manufacturing

- Manufacturing , assembly, and integration of the EQM sensor assembly which will stay at IAP for future testing and analysis purposes
- Manufacturing, assembly, and integration of the Flight Model (FM) of the sensor assembly of the Wave analyzer module for the MAIGRET instrument (delivered to Thales).
- Manufacturing, assembly, and integration of the Flight Model (FM) of the sensor assembly of the Wave analyzer module for the MAIGRET instrument (delivered to Thales).

c) Testing activities

- Functional, thermal vacuum, and vibrational testing of the EQM sensor assembly
- Functional, thermal vacuum, and vibrational testing, as well as the cleanliness and contamination control of the Flight Model (FM) of the sensor assembly of the Wave analyzer module for the MAIGRET instrument.
- Functional, thermal vacuum, and vibrational testing, as well as the cleanliness and contamination control of the Flight Spare Model (FSM) of the sensor assembly of the Wave analyzer module for the MAIGRET instrument.

Project output at the end of the term specified in the PRODEX Experiment Arrangement in terms of:

- Design and documentation contribution to the Structural Model (SM) of MAIGRET, in cooperation with IKI
- Design and documentation contribution to the Thermal Model (TM) of MAIGRET, in cooperation with IKI
- Instrument Electrical Interface Simulator (EIS)of the Wave analyzer module for the MAIGRET instrument (main board, delivered to IKI)
- EQM board which will stay at IAP for future testing and analysis purposes
- Flight Model (FM) of the Wave analyzer module for the MAIGRET instrument (main board and sensor assembly, delivered to IKI).
- Flight Spare Model (FSM) of the Wave analyzer module for the MAIGRET instrument (main board and sensor assembly, delivered to IKI)
- Input to all documentation packages for IKI reviews. IKI will manage the documentation according to Russian standards. No self-standing WAM documentation is foreseen to be delivered at WAM level.

Major Milestones (if any):

- MAIGRET SM and TM delivery – December 2015 (in cooperation with IKI).
- Wave analyzer module EIS delivery to IKI– December 2017.
- Wave analyzer module FM and FSM delivery to IKI/Thales – December 2019.
- Replacement of WAM sensor with a spare model in Thales – July 2021

Appendix 2

FINANCIAL PLAN

Definition and implementation of the Wave analyzer module for the MAIGRET instrument as a part of the European payload element on the Surface Platform of the ExoMars 2022 mission

Institute of Atmospheric Physics, Czech Academy of Sciences

Starting date: December 2015

Ending date: December 2022

INSTITUTE COSTS						**Total**
	Dec 2015-Dec 2017	Jan 2018-Dec 2018	Jan 2019 – Dec 2020	Jan 2021 – Dec 2021	Jan 2022 – Dec 2022	Dec 2015-Dec 2022
Salaries + insurance						
Labor cost	33 591	72391	90644	36792	36000	269418
Small Equipment, components, software	2 291	5243	23319	3098	2000	35951
Services	4 968	5575	23533	7738	3200	45014
Travel	8 802	2059	9074	660	4000	24595
Search coil procurement	0	27346	0	0	0	27346
Institute overhead	18 200	7300	14657	4329	4020	48506
Total	**67 852**	**119 914**	**161 227**	**52 617**	**49 220**	**450 830**

FIGURE 1: Financial Plan in of Euros

FIGURE 2: Equipment purchased via PRODEX between 2016 and 2020 (in Euros), for information only:

Equipment	**Cost (EUR)**
Flight/EM electronic components	321 351
GRLIB License (Cobham-Gaisler)	15 000
Flight PCBs (Invotec)	3653
Total	**340 004**

No further large equipment purchases are planned after 2021.

Total cost to PRODEX (Institute costs + direct purchases by PRODEX): **790 834 EUR** (for information only)

Notes:

1) Funding request is conditional to the selection of Wave analyzer module for the MAIGRET instrument as a part of the European payload element on the Surface Platform of the ExoMars mission.
2) The salaries for the remuneration of work on definition and implementation of Wave analyzer module which will be carried out by IAP personnel: [redacted]
3) Travel expenses are calculated using an average cost of 1000 EUR per person for a short trip. We expect the necessity of 2 trips in 2022, with 2 persons participating, on average.
4) "Small Equipment, components, and software" include the components for development and breadboarding, transport equipment, manufacturing and integration of mechanical parts for the sensor assembly, and necessary licenses for the PCB and FPGA development software.
5) Services include the manufacturing of PCBs for development and breadboarding, fast shipping services, main board and sensor assembly testing expenses, and assembly of the EIS and EQM boards
6) Institute overhead is less than 10%, in accordance with Czech PRODEX rules (http://www.msmt.cz/vyzkum-a-vyvoj/evropska-kosmicka-agentura-program-vyvoje-vedeckych?lang=1)
7) Cost of parts and equipment purchased by PRODEX reflects the reality in January 2022, no further purchases are planned.