THE MICRO-ARES EXPERIMENT AS PART OF THE DREAMS METEOROLOGICAL SUITE ONBOARD SCHIAPARELLI: A PROMISE AND A DEMISE

F. Montmessin, G. Déprez, F. Vivat, R. Hassen-Kodja, P. Granier, L. Lapauw, J.-J. Berthelier, *CNRS LATMOS, UVSQ, Guyancourt, France (franck.montmessin@latmos.ipsl.fr),* **O. Witasse, R. Trautner,** *ESA ESTEC, Noordwijk, Netherlands,* **F. Esposito, C. Molfese,** *INAF, Napoli, Italy,* **S. Debei, A. Aboudan, C. Bettanini,** *CISAS, Padova, Italy***.**

Introduction:

Atmosphere ionization and electrification mechanisms of various sorts are known to exist in most of the planetary environments but the lower atmosphere and surface of Mars combine a number of favorable conditions for the development of intense atmospheric electric fields (henceforth E-fields). This was the original goal of the Micro-ARES sensor, an element of the DREAMS (Dust Characterisation, Risk Assessment, and Environment Analyser on the Martian Surface, see Figure 1) meteorological suite (Esposito et al., 2017), the only scientific payload that equipped the Schiaparelli module onboard the ExoMars 2016 mission. Unfortunately, the Schiaparelli module failed at completing the last phases of its descent after parachute deployment and eventually hit the ground at more than 300 km/h.

Onboard, Micro-ARES was supposed to unveil the yet to be discovered Martian E-fields. Future missions may carry again these kind of sensors and the following text is intended to give a flavour of the science that this kind of instrument may promise for the future.

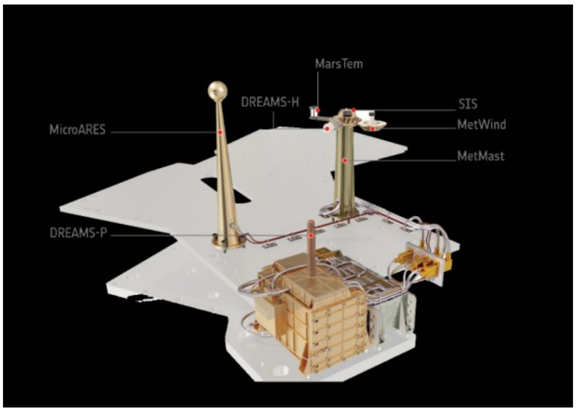

Fig. 1. The DREAMS meteorological suite mounted onboard the Schiaparelli module as part of the ExoMars 2016 landing demonstration attempt (Esposito et al., 2017)

Science Objectives: The main ionization source is the bombardment by cosmic rays, with photo-ionization by solar EUV and soft X-rays contributing on the dayside and above ~ 30 km. The electric conductivity of the atmosphere at ground is estimated at 10^{-11} S/m (Cardnell et al., 2016). In absence of liquid water, the ground conductivity close to the surface should be very small, of the order of 10^{-12} S/m, similar to that of the lunar regolith and contrary to the case of the Earth where the ground can be considered as a perfect conductor. The ionosphere, which constitutes the upper boundary of the global electrical circuit, is conductive, as on the Earth, and close to equipotential.

Several mechanisms can generate electrical charges in the lower atmosphere of Mars. The emission of photo-electrons by solar UV leaves the surface positively charged and the resulting E-field has been estimated to a fraction of Volt/m. The major electrification process appears to be by far impact electrification: dust particles blown by the large atmospheric winds that may occur on Mars inside dust devils (Melnik and Parrot, 1998) or during dust storms collide between themselves and with the surface and exchange charges. It is expected that intense E-fields can build-up, eventually leading to glow discharges or electrical break-down.

The existence of a planetary E-field with very intense local enhancements and possibly significant breakdown currents may have a significant influence on the physics and chemistry of the surface materials, in particular through their control of the photo-electron emission and transport. Even more importantly, the motion of the dust particles themselves depend on the electrical state of the atmosphere. The electrical force exerted on micron size dust particles by the large E-fields generated by dust devils or dust storms may become larger than the drag force due to the wind and therefore control the global transport of dust (Berthelier et al., 2000).

Electrical discharges give rise to intense radio-electric emissions over a wide frequency range from ULF (Schumann resonances) to HF. Electromagnetic waves in the ELF/VLF range may also be generated by the interaction of the solar wind with the ionosphere of Mars and propagate to the ground. AC signals can be generated by dust impacts on the electrodes or on the lander structure and can be detected in a dedicated mode of operation of the instrument.

Measurements. The Micro-ARES experiment was designed to obtain first hand observations in these domains:

- the electric conductivity, its diurnal and seasonal variations and its perturbations following solar events;
- the quasi DC E-field, which reflects the nature

and role of the various charging mechanisms at work on the surface of Mars;

- the ELF/VLF radio-electric emissions that may originate from atmospheric as well as from ionospheric processes and the AC signals from dust particle impacts on the sensors or on the lander structure.

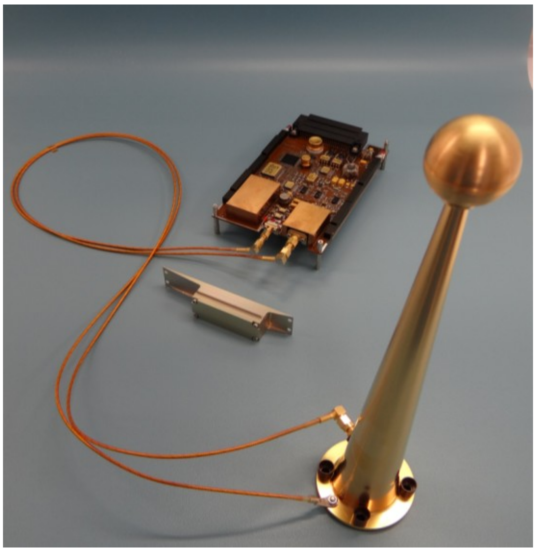

Fig. 2. Picture showing the Flight version of the whole Micro-ARES set-up with the gold-coated antenna harnessed to its PCB.

Experimental Set-up: Micro-ARES is a single probe E-field instrument consisting of a spherical electrode installed on a stiff metallic support (Figures 1 & 2) and a single electronics board housed in the common electronics box of DREAMS inside the warm compartment.

The parent version of Micro-ARES called ARES (proposed in a double probe version, see for instance Berthelier et al., 2000) was validated on two balloon flights and was developed until a Preliminary Design Review as part of the HUMBOLDT platform payload in a previous configuration of ExoMars.

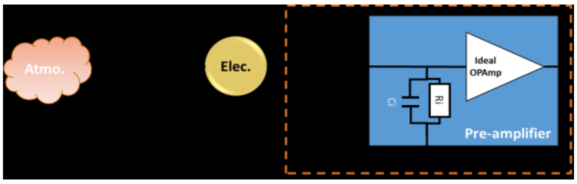

Fig. 3. From Déprez (2017). A schematic model of the Micro-ARES measurement principle. The sphere to atmosphere coupling can be represented by a resistive and capacitive coupling whose R_p and C_p values can be deduced from measurements. T meet the conditions for a floating potential design, the internal impedance R_i has to be >10× R_p. This condition is violated once the resistive bridge (R_L, R_H) is activated.

Micro-ARES measures the amplitude of the vertical component of the E-field in the atmosphere, using the lander potential as a reference. A high impedance (10^{14} Ω) preamplifier is mounted in a voltage follower configuration yielding a precise measurement of the surrounding atmospheric potential in a medium whose resistivity shall be typically >10 smaller than the instrument impedance, as expected for average Martian conditions (Farrell et al., 2015, Cardnell et al., 2016, see Figure 3).

Analog Part. In the Analog portion of the electronics board, the signal is separated in two components: (1) the large amplitude (mV to V) and low frequency (<10 Hz) signal of the DC channel and (2) the small amplitude (10^{-3} mV) and high frequency (100 Hz to kHz) signal of the AC channel. The difference between the two resides in the capacitive coupling of the AC channel with the antenna which effectively suppresses the main component of the signal received from the sphere. The high sensitivity of the AC channel can be used to detect the impacts of charged dust particles to let one infer their horizontal flux and charge distribution.

Probing high electric-fields. A high voltage mode is automatically activated by the Micro-ARES main computer (a Texas Instrument® Digital Signal Processor, hereafter referred as to DSP) when the modulus of the acquired potential exceeds a value of 90V for a certain amount of time (typically a fraction of second). This high voltage mode disrupts the equilibrium of potentials between the antenna and the atmosphere by bifurcating the input signal into a resistive bridge dividing the signal by a factor of >40 and forcing it to cope with the voltage range admitted by the 16 bits ADC.

Conductivity. Operated in the *relaxation probe mode*, the instrument can also provide a measurement of the atmospheric conductivity separately for positive and negative ions. Periodically, a +1V and a -1V pulses are sequentially injected by capacitors into the sphere of the antenna, creating a small and temporary loss of equilibrium between the potential of the antenna and that of the atmosphere surrounding it. Positive and negative ions flowing around the electrode are then attracted by the antenna surface depending on the pulse polarity to fill in the gap of potentials with a characteristic e-folding relaxation time. On the ground, positive and negative conductivities, which can then be subsequently deduced from the evaluation of the relaxation time. Conductivity data consist of DC values averaged with 300 consecutive samples to yield a 20 Hz sampling over 5 seconds. This temporal sampling provides sufficient discretization to infer reliable conductivity.

Data conditioning. Data are acquired and stored by the DSP whose main tasks are setups and commands of the analog part, real time signal processing (data decimation, filtering, selection and conditioning), and ensures communication with the CEU.

Sensitivity: The instrument has a sensitivity in DC mode of 10 mV/m and can sense potential values between -90 to +90 V (the expected corresponding E-fields are +265 and -265 V/m, once averaged between 0 and 25.5cm above the ground) and up to > O(1) kV in high voltage mode. However, deducing E-field values from a single location potential shall account for the antenna and lander geometry. A precise conversion requires detailed modelling of the equipotential perturbations around the sphere.

These perturbations were computed with the COMSOL® software accounting for the exact geometry of lander structure, assuming the atmospheric conductivity is only slightly perturbed by the lander. The model results indicate a slightly different conversion factor than the one obtained straight from the sphere elevation above the ground. A bias of about 20% is found that needs to be incorporated to post-processing on the ground (see Figure 4).

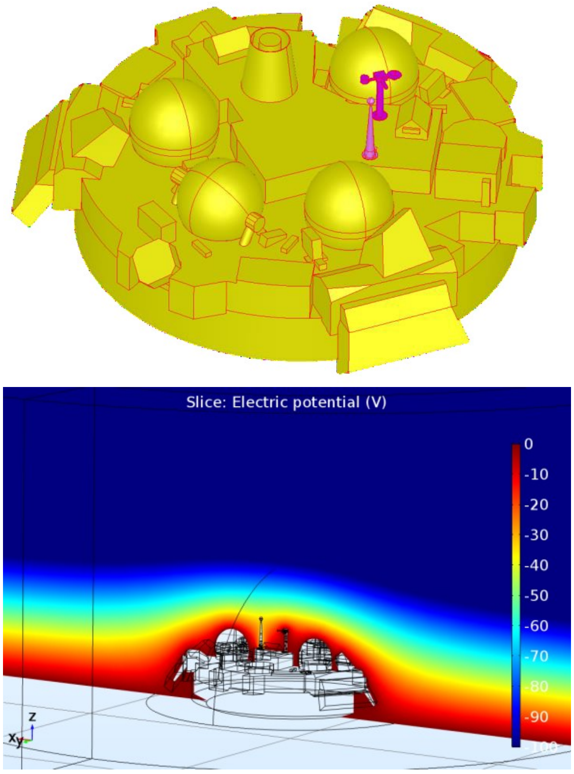

Fig. 4. From Déprez (2017). (top) a CAD model of the lander structure. (bottom) Model of the field lines deformation around the lander in a +100V/m E-field. The resulting electrode potential in these conditions is -33.96 V, yielding a voltage-to-E-field conversion factor of 2.94 m^{-1}, that is close to the ~3.6 m^{-1} conversion factor that would be deduced from the 27.5 cm elevation of the sphere above the lander structure (assumed to be mechanical ground).

Calibration: In the calibration process (Déprez, 2017), signals are always injected in the instrument through a so-called *injection* boxes supposed to reproduce the coupling of the electrode with the atmosphere (Berthelier et al., 2000). These boxes consist of a set of resistances and capacitors mounted in parallel and specified to have resistance and capacitance values close to conditions relevant for the Micro-ARES electrode when immersed in a Martian-like atmosphere.

To calibrate the various components of the instrument part, potential is measured at various test points and the necessary relations (linearity, gain or frequency response) are subsequently established. However, when the test point of the instrument measurement is used (in Least Significant Bits, LSB) the value and error are respectively derived from the average and standard deviation of a measurement set. The uncertainties are then propagated by fitting the data with adequate functions, using the least-square method to take into account the uncertainties of all inputs.

DC Channel. The DC chain was calibrated during Thermal vacuum tests, with temperatures ranging from 45°C to -35°C (every 5°C). The DC linearity at each temperature with each Injection box and at 17 steps was measured between -80V and +80V.

AC Channel. The AC channel calibration has been performed only at 20°C, since the noise conditions and access to the instrument board during the TVT was limited. Calibration consisted in measuring the frequency response, both in gain and phase, of the whole electronic circuit.

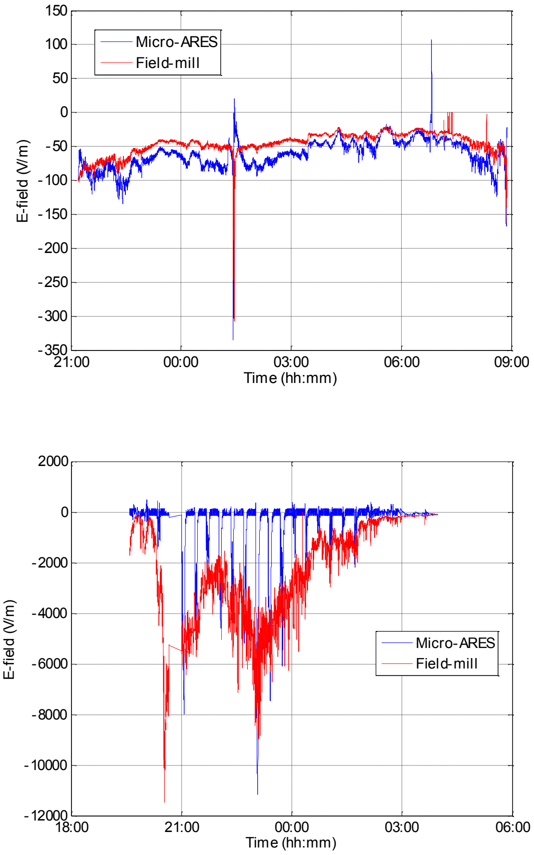

Fig. 5. From Déprez (2017). (top) Comparison of E-field measurements performed by Micro-ARES in the Moroccan desert in the summer 2014 and those of a commercial E-field mill used here as a reference. During calm weather conditions, E-field evolution can be disrupted by

dust devil passage creating, short spikes. (bottom) in conditions of dust storms, E-fields remain elevated for several hours, such length that Micro-ARES can only sample for 20% of the time due to its self-limiting power consumption functionality, since the high voltage mode induces a threefold increase of the power demand that needed to be jugulated once at Mars

Terrestrial testing: During the summer of 2014, a prototype version of Micro-ARES was involved in a meteorological measurement campaign led by the DREAMS to tentatively replicate the dust conditions met on Mars. The experiment site was located in a valley with a dark, flat and compact soil made of a compact mixture of dust sand and silt, conducive to heating and thus formation of dust devils and dust storms. The valley was flanked at the east and west by two ergs of dunes made of typical desert sand (quartz/silicate). The composition of the ground is of importance since the produced dust electrical behavior is dependent on their mineral state and composition. Most triboelectricity models (Melnik and Parrot, 1998; and Desch, 2000) do rely on a mixture of dust grains of different composition on which depends the triboelectric potential difference property. This location was selected because of the high likelihood of dust storms and dust devil occurrence in this period of the year (June-August, the hottest months). In order to produce DREAMS-like measurement, the team already prepared a setup measuring the windspeed in 2D (at 50 cm, 1,5 m and 4 m above the ground), the atmospheric pressure, air temperature, dust concentration, illumination and an E-field measurement device, an oscillating field-mill measuring every second the E-field at two meters above the ground. This calibrated and reliable instrument (Campbell scientific CS110) was installed on top of a 2 m mast and was used as a DC reference for the concomitant Micro-ARES prototype measurements.

Micro-ARES and the Field-mill exhibited remarkable agreement (Figure 5), noting though that both were put more than 50 meters a part and with a 1.5 meter elevation difference.

Conclusions: A small, compact, easily accommodable E-field sensor developed and mounted onboard the *Schiaparelli* module of the ExoMars 2016 mission has been presented. While the failure of *Schiaparelli* meant that Micro-ARES missed the opportunity to perform the first ever E-field measurement at Mars, it set the ground for future applications onboard spaceborne platforms. Its design allows for a variety of scientific explorations and may very well be re-used “as is” for upcoming Mars missions.

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