Publications of the Institute of Geophysics, Polish Academy of Sciences
Geophysical Data Bases, Processing and Instrumentation
vol. 425 (M-32), 2019, pp. 63-67
DOI: 10.25171/InstGeoph_PAS_Publs-2019-012
"Electromagnetic ULF/ELF Fields on Earth and in Space" Conference, Warsaw, Poland, 2019

ELF Exploration of Mars

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1. INTRODUCTION

Recently, due to a start of extensive space exploration, studies on propagation of electromagnetic waves in other bodies in the Solar System have become an important issue. In Martian exploration especially useful can be waves in extremely low frequency (ELF, 3Hz – 3 kHz) range. Attenuation of these waves in the Martian environment is very low, and they can propagate around the globe in a cavity, made of two high-conductivity spherical layers: the ionosphere and the ground. On Mars, as there is no liquid water at the planetary surface, the high-conductivity layers of the ground are located in the subsurface. Therefore, ELF waves can propagate to the depth of many kilometers. In the Martian atmosphere, ELF waves can be generated by dust events, such as dust storms and dust devils, which are important factors influencing global atmospheric circulation. If ELF sources occur on Mars, an ELF station can be used as a tool to investigate not only the properties of the ionosphere, but also atmosphere, and the subsurface of Mars.

2. THE IMPORTANCE OF MARS ELF EXPLORATION

Even if ELF exploration of Mars can be related to many issues, e.g., daily dynamics of the ionosphere or global circuit existence, in this work, I will focus only on two goals of this exploration: measurements of ELF sources, and detection of underground liquid water.

2.1 ELF sources on Mars

The first goal of any Mars ELF exploration will be detection of ELF sources. Electrical discharges in the atmosphere of Mars can be related to triboelectric processes, associated with aeolian transport of sediments.

On the basis of ground-based telescopic data, which have been acquiring over more than 100 years, it has been found that global dust storms on Mars occur every few years (Martin and Zurek 1993), regional every few weeks, and local every day (Cantor *et al*. 2001). Local storms last a day, regional several days, global many weeks.

Martian dust devils can reach more than 10 km in height and a kilometer in diameter, whereas on Earth they are not higher than 2.5 km and not wider than 150 m (Fisher *et al*. 2005, Greeley *et al*. 2006). Dust devils are present in all latitudes and elevations. They tend to occur during local spring and summer, with a peak in midsummer (Cantor *et al*. 2006).

Characteristics of discharges related with dust events are still unknown, although many experimental (Eden and Vonnegut 1973, Qu *et al*. 2004, Forward *et al.* 2009, Aplin *et al*. 2012), numerical (Kok and Renno 2009), and field test studies (Freier 1960, Stow 1969, Farrell *et al.* 2004) have been dedicated to investigate phenomena of electricity generate by aeolian transport.

On Earth, Stow (1969) observed upward-pointing electric fields up to 200 kV/m at the ground level during dust storms in the Sahara desert. The electric and magnetic observation of terrestrial dust devils have indicated presence of quasi-static DC electric fields of the order of 1-100 kV/m (Freier 1960, Farrell *et al.* 2004), AC currents, and ELF emission (Houser *et al*. 2003).

Observations of electrical discharges in the Martian atmosphere are also non-conclusive. In 2006, Ruf *et al*. (2009) conducted some research in the microwave range using a 34 m parabolic antenna of the Deep Space Network. They observed unusual pattern of radiation, emitted in minutes-long bursts, when a regional dust storm was present on Mars. Anderson *et al*. (2012) performed similar observation using the Allen Telescope Array in 2010. They found similar variations. However, this variability spread across a broad spectrum and was driven by narrow-band radio frequency interferences. Gurnett *et al*. (2010) stated that during five-year search with the MARSIS (Mars Advanced Radar for Subsurface and Ionosphere Sounding) instrument, working on board Mars Express mission, no radio signals associated with discharges was discovered although during this period two major and several regional storms occurred.

ELF measurements from the planetary surface can easily resolve this issue, as even weak sources should be possible to detect from large distances (Kozakiewicz *et al.* 2016). It is highly probable that discharge intensity on Mars is weaker than on Earth, and also subjected to seasonal variations related to dust activity. Therefore, measurements of ELF source can be used also to improve Martian global atmospheric circulations models, which must include influence of dust on the atmosphere dynamics.

2.2 Underground water

The second important goal of ELF studies on Mars is to create an instrument capable of detecting subsurface layers rich in liquid water, a crucial issue in the search for life.

Certainly, underground water exploration can be conducted using seismic waves or radar frequencies, but these techniques have some disadvantages. Mars seismic activity is believed to be very low, as Mars is a geologically inactive planet. First marsquake, detected by the Seismic Experiment for Interior Structure (SEIS) instrument on Insight lander in April 2019, was very small. In addition, the abovementioned detection was the only one detection during first two months of this seismic investigation (more about SEIS, see Lognonné *et al.* 2019). Up till now more successful has been an exploration done by MARSIS (Mars Advanced Radar for Subsurface and Ionosphere Sounding) onboard Mars Express mission, which have resulted in highly probable detection of liquid water under south polar glacial layers. Orosei *et al.* (2018) indicated that a bright feature visible in the instrument's results has high relative dielectric permittivity (>15) that can be interpreted as a stable body of liquid water. However, radar sounding gives the best results almost solely in polar areas, due to dielectric properties of ices, regolith, and rocks, and future Mars exploration is planned almost solely in equatorial regions, where insolation and temperature is much higher. Therefore some other methods have been proposed.

One of these methods is ELF prospecting (Kozakiewicz *et al.* 2016). Only in cases of a high-conductivity planetary surface, like on Earth, the ground has very little influence on ELF propagation. For conductivities slightly lower than 10^{-4} S/m, ELF waves propagate under the planetary subsurface, and can be used as a tool for underground exploration (Kozakiewicz *et al*. 2015). On Mars, as there is no liquid water at the surface, the upper parts of the lithosphere must be characterized by low conductivity values, ca. 10^{-7} S/m (Berthelier *et al*. 2000). Therefore, if there is underground water, which greatly increases subsurface conductivity, than its presence should be easily indicated in ELF measurements (Kozakiewicz *et al*. 2015).

3. CONCLUSIONS AND FUTURE PLANS

Many authors have studied Schumann resonance phenomenon on Mars (Sukhorukov 1991, Pechony and Price 2004, Molina-Cuberos *et al.* 2006, Yang *et al.* 2006, Soriano *et al.* 2007, Kozakiewicz *et al.* 2015, Toledo-Redondo *et al*. 2017, Haider *et al*. 2019), as it is a very informative tool in planetary exploration because of its global nature (Berthelier *et al*. 2000, Aplin *et al*. 2008, Harrison *et al*. 2008). But even if Schumann resonance are not generated on Mars, or generated only seasonally, the intensity of dust activity on Mars should provide enough ELF signals to measure the properties of the Martian cavity; under the assumption that Mars dust events generate ELF waves.

For Martian ELF investigation to become a reality, it is necessary to prove its capabilities on Earth. A prototype of ELF Martian station should be tested in terrestrial desert environments in order to measure signals in ELF range generated by electrical discharges in dust storms, and to study an impact of aeolian transport, including dust deposition and sand saltation, on the operating characteristic of the station.

Acknowledgments. This work has been supported by the National Science Centre Grant: 2015/19/B/ST9/01710.

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BADANIE MARSA ZA POMOCĄ FAL ELF

Streszczenie

W środowisku marsjańskim fale elektromagnetyczne ekstremalnie niskich częstotliwości (ELF, Extremely Low Frequency, 3 Hz – 3kHz) są słabo tłumione i mogą się propagować dookoła planety we wnęce ograniczonej z jednej strony przez jonosferę, a z drugiej przez przewodzące warstwy gruntu. Badania prowadzone za pomocą stacji ELF na Marsie mogą mieć nieco inne zastosowanie niż na Ziemi, ze względu na to, iż fale ELF wnikają w grunt marsjański na znacznie większe głębokości niż ma to miejsce na Ziemi. W związku z tym możliwe jest badanie za pomocą fal ELF warstw podpowierzchniowych Marsa. Ponadto prawdopodobnym źródłem fal ELF na Marsie są wyładowania elektryczne generowane przez burze i diabełki pyłowe, z czego wynika, że pomiary ELF mogą pomóc w badaniach aktywności pyłowej, która w znacznej mierze wpływa na globalne właściwości atmosfery Marsa.