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MASTER THESIS

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Detection of 2D features in MARSIS ionogram pictures

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Název práce: Hledání 2D jevů v ionografických snímcích přístroje MARSIS

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Abstrakt: Práce se zabývá technikami hledání význačných prvků v ionogramech zachycených přístrojem MARSIS umístěným na kosmické sondě Mars Express. Ionogramy jsou reprezentovány jako dvourozměrné obrázky s hodnotou kódovanou pomocí barvy. Vyvíjené techniky se snaží detekovat v takových snímcích různé zajímavé křivky (definované sadou parametrů), případně měřit další parametry nalezených objektů (perioda opakování přímek).

Klíčová slova: rozpoznávání vzorů, detekce, parametrické křivky, Mars Express, vektorizace

Title: Detection of 2D features in MARSIS ionogram pictures

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Abstract: The work focuses on techniques for finding significant features in ionograms captured by the MARSIS instrument onboard the Mars Express spacecraft. Ionograms are 2D images with values represented in color. The developed techniques try to detect interesting curves (parametrically defined) in such images and measure some more parameters of the found objects (like the repetition period of lines).

Keywords: pattern recognition, detection, parametric curves, Mars Express, vectorization

Contents

Introduction

1. Mars Express, MARSIS and ionograms

1.1 Mars Express

First of all, let us briefly introduce the spacecraft carrying all the equipment needed to acquire ionograms. Its name is *Mars Express* (MEX) and it was launched by the *European Space Agency* (ESA) on 2 June 2003.

MEX arrived to Mars at its orbit with periapsis 250 km and apoapsis over 11000 km on 25 December 2003 [25] with seven onboard scientific instruments and a landing module called Beagle 2. We're going to take a look at all of them in the following subsections; just Beagle 2 description is going to be rather short, because the landing sequence failed (for an unknown reason) and the lander didn't establish connection after it landed (if it landed at all)[25, p. 4].

The mission of MEX has several goals like "global studies of the surface, subsurface and atmosphere at unprecedented spatial and spectral resolutions" [25, p. viii]. One of the goals, however, stands out among all the others. It is the search for water (or its traces) on martian surface or subsurface.

Why water? There is lots of geological evidence of former water occurrence. But before the MEX mission nobody had proved or refuted presence of water on Mars in the present. Knowing more about water on Mars and its history, the scientists could postulate better hypotheses about the possibility of (former) life on the planet [25, p. ix].

The original mission lifetime of MEX was projected up to the end of 2005 (which would be 1 Martian year = 687 Earth days) [7]. However, overcoming some small problems (as the Solid State Mass Memory anomalies described in [11] or the MARSIS antennas deployment problems in 2004 [8, 9]), MEX has worked on its science goals up to this day and its science mission was extended until 2014 [13] (after 3 preceding similar extensions). Fred Jansen, MEX mission manager, said MEX had enough fuel for another 14 years of operation (at the beginning of 2012) [5]. So there is a hopeful prospect of further and even deeper Mars exploration (eg. [15] discovered an unexpected way of using the MARSIS instrument so that they "added magnetometer functionality" to MARSIS).

In the next subsections you can find out more about particular MEX instruments. The descriptions are based on [25] which you can see for more detailed information.

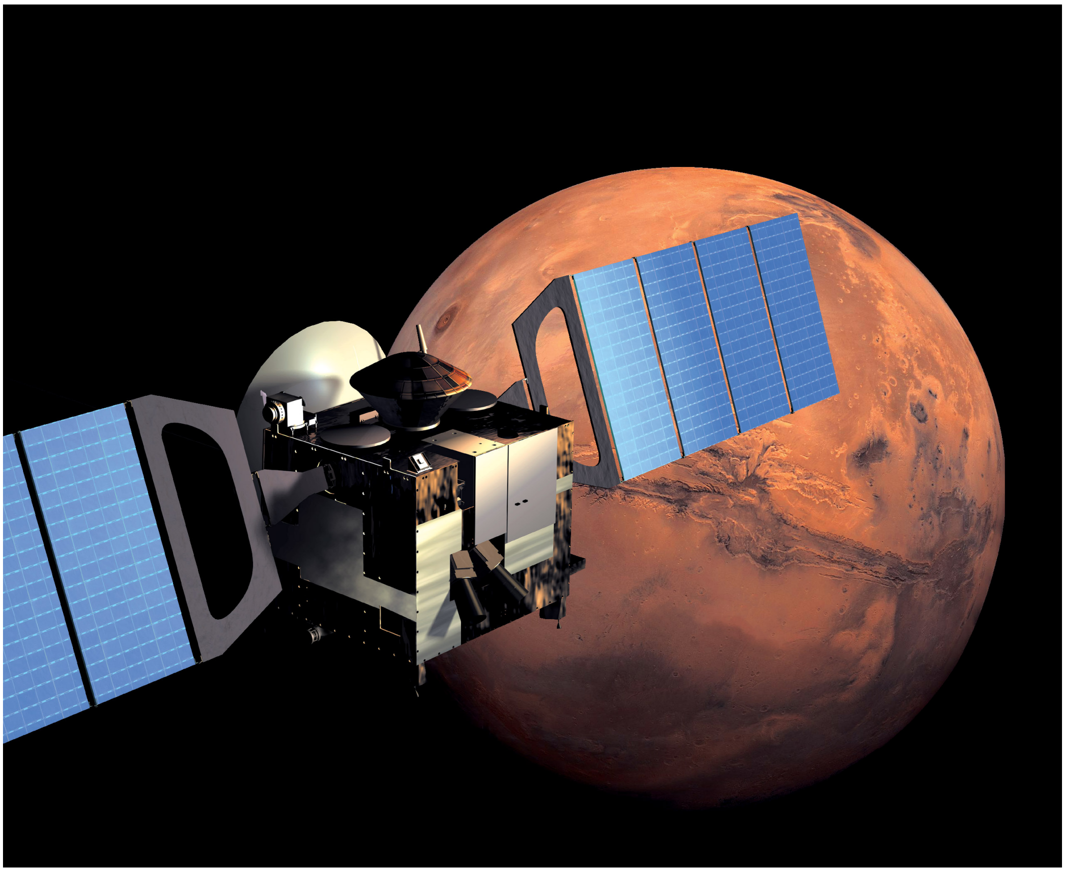

Figure 1.1: Mars Express spacecraft. Credit: ESA [10]

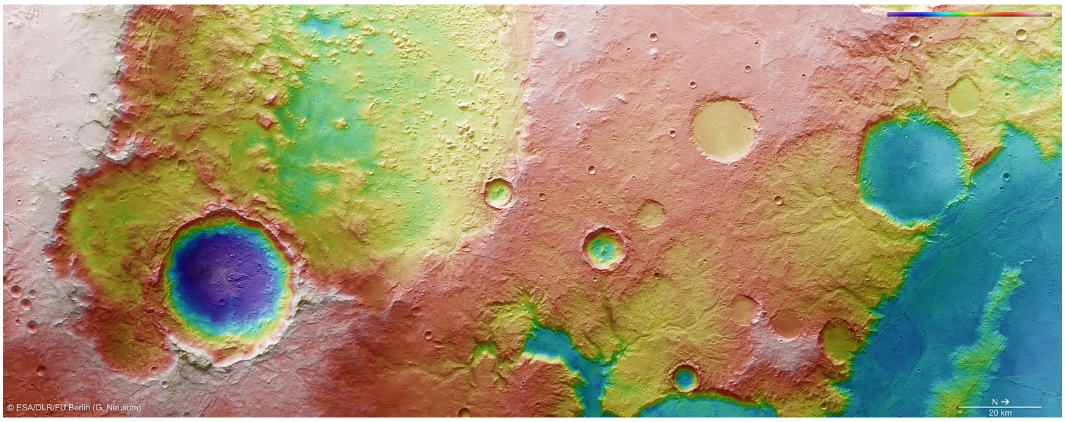

Figure 1.2: Example image taken by HRSC. Credit: ESA/DLR/FU Berlin (G. Neukum) [22]

1.1.1 HRSC (*High–Resolution Stereo Camera*)

HRSC is a high–resolution pushbroom[1] camera for surface imaging. Its goals are to characterize surface structure and morphology at resolution 10 m px^{-1} (regions of interest at 2 m px^{-1}), surface topology at high vertical resolution, atmospheric phenomena, physical properties of the surface and to classify terrain and to refine the martian cartographic base. It is also intended to observe martian moons Phobos and Deimos during their approaches.

HRSC is able to capture the surface at resolution up to 10 m px^{-1} with field of view 11.9°, covering a 52.2 km wide strip of surface at height 250 km (which is the periapsis of MEX). The camera consists of 9 CCD sensors allowing it to acquire triple stereo images in 4 colors and 5 phase angles. What is a very useful property of these images, is that they are taken nearly simultaneously and thus having the same illumination and other observational conditions (which further helps in photogrammetric processing of the images).

HRSC also contains a super–high–resolution camera called SRC (*Super–Resolution Channel*) aimed at targeted observations of particular surface details. With image resolution 2.3 m px^{-1} and field of view 0.54° it provides a detailed view of a 2.3x2.35 km large surface. Its main purpose is to take details of places of interest, eg. future landing sites for other landing modules.

Up to November 2011 HRSC had covered about 88% of the martian surface [12, pp. 72–73] and still continues to gather new data. The scientific results of HRSC are for example better exploration of fluviatile valleys [19], dicovery of numerous glacial landforms, investigating lava flows, dicovery of "dust devils" (fast moving dust storms) or providing data to derive a detailed topographic model of more than 20% of Phobos [16, pp. 945–949].

[1] A camera that scans the image by rows perpendicular to the flight direction. See `http://earthobservatory.nasa.gov/Features/EO1/eo1_2.php` for more details.

1.1.2 OMEGA (*Observatoire pour la Minéralogie, l'Eau, les Glaces et l'Activité*)

OMEGA is a medium– and high–resolution spectrometer operating in visible and near–IR spectra (0.38–5.1 μm wavelength). Its medium–resolution operating mode (from heights of 1500 to 4000 km) can measure with the resolution 2–5 km targeting at global surface coverage, while the high–resolution mode (from the close vicinity of periapsis) brings resolution 350 m or better, but will cover only a small fraction of the surface.

As stated in [25, pp. 38–39], the main goals are to study the evolution of Mars, to detect minerals hidden to lower resolutions, to map mineralogical boundaries between geological units, to reveal gradients in hydration minerals related to fossil water flows and to monitor features associated with wind transportation. In particular, it is intended to find carbonates (not found on martian surface until the launch of MEX) and water ice. It is also able to measure atmospheric pressure, CO and H_2O column densities and surface temperature.

Recent contributions of the OMEGA payload are e.g. confirmation of liquid water on the surface when the planet was young [17], discovery of infrared and ultraviolet glows in the atmosphere [2], proving that Mars had a hot and wet period [4] (implying there were lots of greenhouse gases and a strong magnetic field, too [14, p. 90]), analyzing the south polar cap and finding out it is formed mainly of water ice [6], observation of CO_2 ice clouds [21] or finding ferric oxides near the equator [20].

1.1.3 MARSIS (*Mars Advanced Radar for Subsurface and Ionosphere Sounding*)

MARSIS is a long–wavelength radar using coherent wide-band pulses for sounding of the surface, subsurface and ionospehere of Mars. For these purposes it uses a 40 m dipole antenna (for both transmitting and receiving) and a shorter 7 m monopole antenna (only for receiving). Due to the used sounding frequencies ranging from 100 kHz to 5.5 MHz it is able to reach the depth about 5–8 km under the surface.

The primary goal of MARSIS is to detect liquid and solid water in the upper crust of Mars. There are also other objectives: subsurface geologic probing (to make a 3D characterization of the subsurface structures), surface characterization (to measure surface roughness, reflectance to radar signals and to estimate topography) and ionosphere sounding (to measure interaction between solar wind and the ionospehere) [25, p. 51].

To name some results of the MARSIS instrument, we can mention revealing the layered subsurface structure of both polar caps (strongly suggesting there were oceans in distant history at these places) [14, pp. 98–102] along with estimating the volume of subsurface water ice in the polar cap [24], discovery of Medusae Fossae Formations (the youngest surface deposits) [14, pp. 102–105] or mapping the ionosphere and verifying the ionospheric density models [14, pp. 105-110].

One surprising and unexpected utilization of the MARSIS instrument is given by the electron cyclotron echoes found in ionograms (see section 1.3.1). It was found that often they correspond to the strength of the magnetic field, effectively allowing to measure that field and compare it to its model. Another type of echoes, the oblique ionospheric echoes (see section 1.3.2) were identified to correspond to the crustal magnetic field. Both these contributions were made by [15].

1.1.4 PFS (*Planetary Fourier Spectrometer*)

PFS is IR–spectrometer (based on double–pendulum interferometer) operating in the range 1.2–45 μm divided into two channels – the *Short Wavelength* (SW) channel (1.2–5 μm) and the *Long Wavelength* (LW) channel (5–42 μm). Its spatial resolution is 10 km for SW and 20 km for LW (from altitude 300 km). PFS uses an onboard *Fast Fourier Transform* circuit to select only the data scientists are interested in.

The objectives of this device are atmospheric studies like atmospheric composition (as it can detect eg. H_2O, CO and CO_2 spectra), solid–phase surface components detection and atmospheric dust measurements. PFS also captures the vertical temperature–pressure profiles and dust and ice opacity [25, pp. 115–116].

The contributions made using PFS so far are for example measuring the atmospheric temperature (finding out that there is a rather complicated situation around the peak of Olympus Mons), measuring the surface temperature, counting the atmospheric dust content, observing temperature inversion effects, detecting methane in the atmosphere (which could imply either organic life or volcanic activity, which are both unexpected phenomena), proving that the south polar cap is made mainly from CO_2 ice, or capturing the solar spectrum from the surroundings of Mars (which cannot be done from Earth) [25, pp. 122–135].

1.1.5 SPICAM (*SPectroscopy for the Investigation of the Characteristics of the Atmosphere of Mars*)

The SPICAM instrument is made of two spectrometers, one operating in the UV spectrum (118–320 nm) and the other in the near–IR (1.0–1.7 μm).

Many tasks have been assigned to SPICAM, the major of them being investigating ozone, H_2O and aerosols vertical profiles in the atmosphere. These should help constructing meteorological and dynamical atmospheric models, understanding the water vapour atmospheric cycles, characterize processes of water escape from the atmosphere, investigating the interactions between surface and atmosphere and revealing impact of aerosols on martian climate [25, pp. 97–100].

One of the latest surprises brought by SPICAM is martian atmosphere is supersaturated with water vapour which further prepares conditions for water escape from the atmosphere [18]. Another unexpected result are nocturnal aurorae observed in the upper atmosphere, along with the (expected) NO recombination nightglow [3]. Other results involve retrieving global spatial and temporal climatology of ozone [23], south polar cap observations [14, pp. 158–159], studies of UV dayglow [14, pp. 160–162], constructing the aerosol vertical profiles [14, pp. 175–180] or observation of CO_2 clouds on the nightside [14, p. 178].

1.1.6 ASPERA–3 (*Analyser of Space Plasmas and EneRgetic Atoms*)

ASPERA–3 is an instrument designed to study the interaction between solar wind and martian atmosphere. It comprises of four separate detectors. The first one is *Neutral Particle Imager* (NPI) measuring the *energetic neutral atom* (ENA) flux with high angular resolution. Another one neutral atoms sensor, the *Neutral Particle Detector* (NPD), measures the neutral atom flux resolving energy and mass of the atoms. The other two instruments are aimed at electrically charged particles. The *Electron Spectrometer* (ELS) is a top–hat electrostatic analyzer, while the *Ion Mass Analyzer* (IMA) is an ion mass composition analyzer working with H^+, He^{2+}, He^+ and O^+ ions [25, p. 122].

ASPERA–3 should focus on measuring ENAs in order to investigate the interaction between solar wind and martian atmosphere, to characterize the impact of plasma processes on atmospheric evolution and to obtain plasma and neutral gas distribution near Mars. It should also measure electrons and ions to complement ENA measurements, to study the dynamics and structure of plasma and to provide solar wind parameters [25, p. 122].

To present some results of ASPERA–3 we can mention discovering that the solar wind penetrates much deeper in martian atmosphere than was believed, being one of the atmospheric ions escape mechanisms [1], detection of ENA jets caused by solar wind [14, pp. 208–209], observing the ENA flux during Mars eclipse which laid foundation of a new method to measure planetary exosphere [14, p. 209] or proving there is a yet unidentified source of interplanetary ENAs [14, pp. 209–212].

1.1.7 MaRS (*Mars Express Orbiter Radio Science*)

1.1.8 Beagle 2

1.2 MARSIS

1.3 Ionograms

1.3.1 Electron cyclotron echoes

1.3.2 Oblique ionospheric echoes

2. Title of the second chapter

2.1 Title of the first subchapter of the second chapter

2.2 Title of the second subchapter of the second chapter

Conclusion

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