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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. Vyvinuté techniky se snaží detekovat v takových snímcích různé zajímavé křivky (definované sadou parametrů), případně měřit další parametry nalezených objektů (perioda opakování přímků).

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

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# 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 [21] 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)[21, p. 4].

The mission of MEX has several goals like “global studies of the surface, subsurface and atmosphere at unprecedented spatial and spectral resolutions” [21, p. viii]. One of the goals, however, stands out among all the others. It is the search for water (or its traces) on Mars' 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 [21, 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) [5]. However, overcoming some small problems (as the Solid State Mass Memory anomalies described in [9] or the MARSIS antennas deployment problems in 2004 [6, 7]), MEX has worked on its science goals up to this day and its science mission was extended until 2014 [11] (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) [3]. So there is a hopeful prospect of further and even deeper Mars exploration (eg. [13] 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 [21] which you can see for more detailed information.

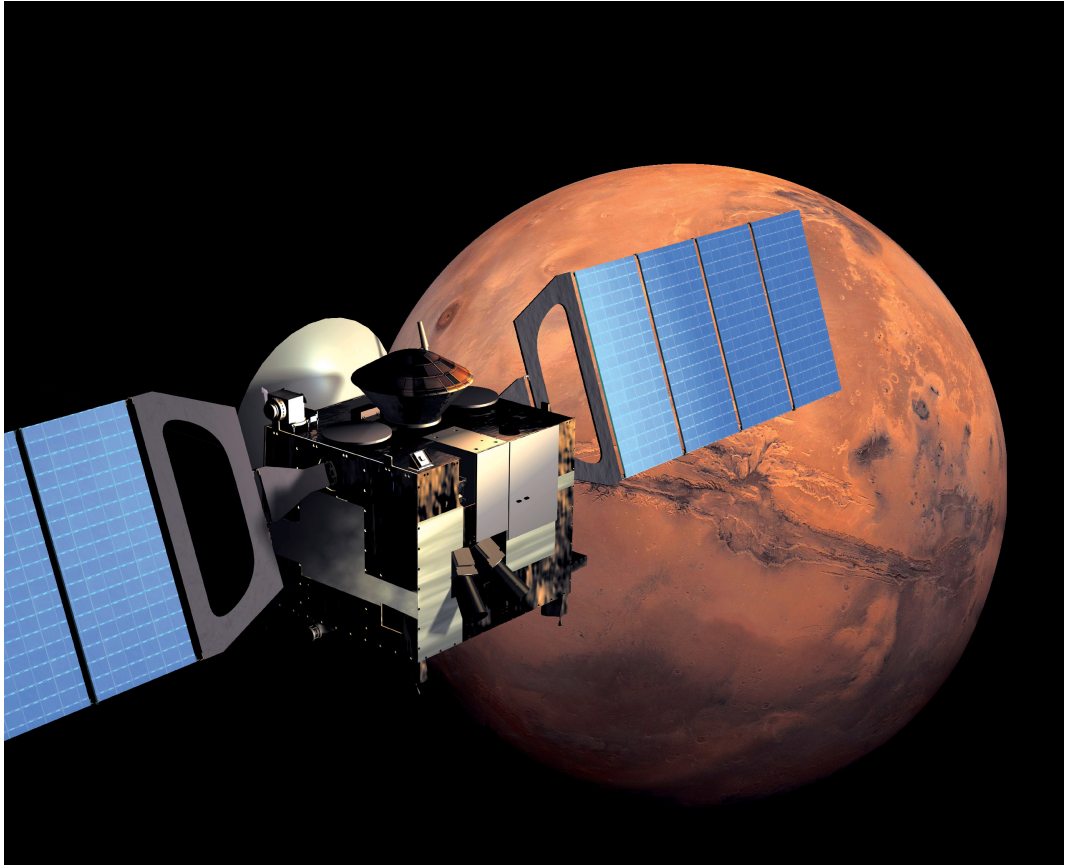


Figure 1.1: Mars Express spacecraft. Credit: ESA [8]

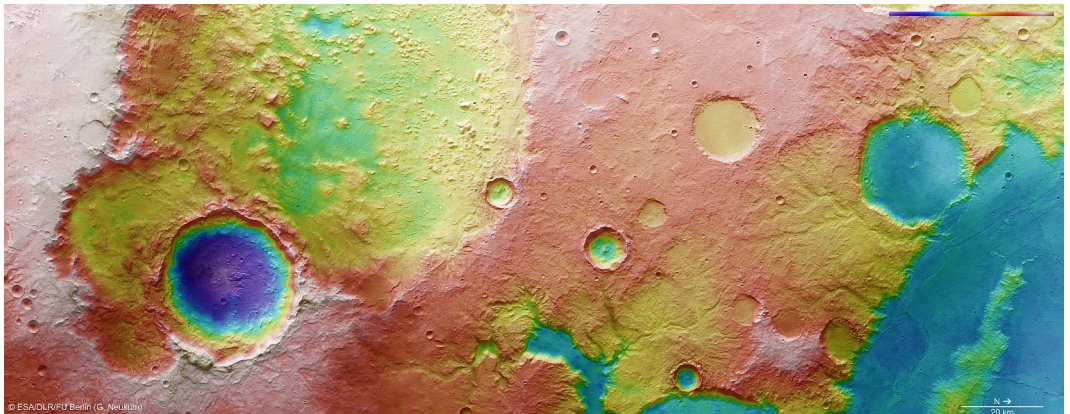


Figure 1.2: Example image taken by HRSC. Credit: ESA/DLR/FU Berlin (G. Neukum) [19]



### 1.1.1 HRSC (*High-Resolution Stereo Camera*)

HRSC is a high-resolution pushbroom<sup>1</sup> camera for surface imaging. Its goals are to characterize surface structure and morphology at resolution 10 m px<sup>-1</sup> (regions of interest at 2 m px<sup>-1</sup>), 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 Mars' moons Phobos and Deimos during their approaches.

HRSC is able to capture the surface at resolution up to 10 m px<sup>-1</sup> 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<sup>-1</sup> 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 [10, pp. 72–73] and still continues to gather new data. The scientific results of HRSC are for example better exploration of fluvial valleys [16], discovery of numerous glacial landforms, investigating lava flows, discovery of “dust devils” (fast moving dust storms) or providing data to derive a detailed topographic model of more than 20% of Phobos [14, pp. 945–949].

### 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 [21, 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

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<sup>1</sup>A camera that scans the image by rows perpendicular to the flight direction. See [http://earthobservatory.nasa.gov/Features/E01/eo1\\_2.php](http://earthobservatory.nasa.gov/Features/E01/eo1_2.php) for more details.

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<sub>2</sub>O 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 [15], discovery of infrared and ultraviolet glows in the atmosphere [1], proving that Mars had a hot and wet period [2] (implying there were lots of greenhouse gases and a strong magnetic field, too [12, p. 90]), analyzing the south polar cap and finding out it is formed mainly of water ice [4], observation of CO<sub>2</sub> ice clouds [18] or finding ferric oxides near the equator [17].

### 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 ionosphere 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 ionosphere) [21, 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) [12, pp. 98–102] along with estimating the volume of subsurface water ice in the polar cap [20], discovery of Medusae Fossae Formations (the youngest surface deposits) [12, pp. 102–105] or mapping the ionosphere and verifying the ionospheric density models [12, 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 [13].

#### 1.1.4 PFS (*Planetary Fourier Spectrometer*)

PFS is IR-spectrometer (based on double-pendulum interferometer) operating in the range 1.2–45  $\mu\text{m}$  divided into two channels – the *Short Wavelength* (SW) channel (1.2–5  $\mu\text{m}$ ) and the *Long Wavelength* (LW) channel (5–42  $\mu\text{m}$ ). 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.  $\text{H}_2\text{O}$ , CO and  $\text{CO}_2$  spectra), solid-phase surface components detection and atmospheric dust measurements. PFS also captures the vertical temperature–pressure profiles and dust and ice opacity [21, pp. 115–116].

The contributions made from PFS data 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  $\text{CO}_2$  ice, or capturing the solar spectrum from the surroundings of Mars (which cannot be done from Earth) [21, pp. 122–135].

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

#### 1.1.6 ASPERA (*AnalysER of Space Plasmas and ENeRgetic Atoms*)

#### 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

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# Conclusion

# Bibliography

- [1] BERTAUX, J. L. et al. First detection of O 2 1.27  $\mu$  m nightglow emission at Mars with OMEGA/MEX and comparison with general circulation model predictions. *Journal of Geophysical Research*. March 2012, 117, pages E00J04. ISSN 0148-0227. doi: 10.1029/2011JE003890. Available from: <http://www.agu.org/pubs/crossref/2012/2011JE003890.shtml>.
- [2] CHEVRIER, V., POULET, F., BIBRING, J.-P. Early geochemical environment of Mars as determined from thermodynamics of phyllosilicates. *Nature*. July 2007, 448, 7149, pages 60–3. ISSN 1476-4687. doi: 10.1038/nature05961. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/17611538>.
- [3] CLARK, S. *Mars Express back in business at the red planet*. In *Spaceflight Now* [online], 2012. [Accessed 03/20/2013]. Available from: <http://www.spaceflightrightnow.com/news/n1202/15marsexpress/>.
- [4] DOUTÉ, S. et al. South Pole of Mars: Nature and composition of the icy terrains from Mars Express OMEGA observations. *Planetary and Space Science*. January 2007, 55, 1-2, pages 113–133. ISSN 00320633. doi: 10.1016/j.pss.2006.05.035. Available from: <http://linkinghub.elsevier.com/retrieve/pii/S0032063306001243>.
- [5] ESA. MARS EXPRESS MASTER SCIENCE PLAN Part I - Introduction. Technical Report 1, 2004. Available from: <http://www.rssd.esa.int/SB/MARSEXPRESS/docs/MSPDOC/MSP0verviewDocumentation-PartI.pdf>.
- [6] ESA. *Mars Express Radar Deployment Postponed*. In *ESA Science & Technology* [online], 2004. [Accessed 03/20/2013]. Available from: <http://sci.esa.int/science-e/www/object/index.cfm?fobjectid=35021>.
- [7] ESA. *Mars Express 2nd Boom Deployed*. In *ESA Science & Technology* [online], 2005. [Accessed 03/20/2013]. Available from: <http://sci.esa.int/science-e/www/object/index.cfm?fobjectid=37608>.
- [8] ESA. *Mars Express and the mystery of Phobos*. In *ESA Kids Liftoff* [online], 2010. [Accessed 03/20/2013]. Available from: [http://www.esa.int/esaKIDSen/SEM8534KV5G\\_Liftoff\\_1.html](http://www.esa.int/esaKIDSen/SEM8534KV5G_Liftoff_1.html).
- [9] ESA. *Mars Express steadily returns to routine operation*. In *ESA Our Activities* [online], 2011. [Accessed 03/20/2013]. Available from: [http://www.esa.int/Our\\_Activities/Operations/Mars\\_Express\\_steadily\\_returns\\_to\\_routine\\_operation](http://www.esa.int/Our_Activities/Operations/Mars_Express_steadily_returns_to_routine_operation).

- [10] ESA. Programmes in Progress. *Bulletin Space for Europe issue 148*. 2011, pages 72–73. Available from: <http://esamultimedia.esa.int/multimedia/publications/ESA-Bulletin-148/pageflip.html>.
- [11] ESA. *Fact Sheet*. In *ESA Science & Technology* [online], 2013. [Accessed 03/20/2013]. Available from: <http://sci.esa.int/science-e/www/object/index.cfm?fobjectid=47364>.
- [12] FLETCHER, K., WITASSE, O. *MARS EXPRESS: The Scientific Investigations*. Noordwijk, Netherlands : ESA Communication Production Office ESTEC, PO Box 299, 2200 AG Noordwijk, Netherlands, 2009. Available from: <http://sci.esa.int/science-e/www/object/index.cfm?fobjectid=47218>. ISBN 978-92-9221-975-8.
- [13] GURNETT, D. a. et al. Radar soundings of the ionosphere of Mars. *Science (New York, N.Y.)*. December 2005, 310, 5756, pages 1929–33. ISSN 1095-9203. doi: 10.1126/science.1121868. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/16319123>.
- [14] JAUMANN, R. et al. The high-resolution stereo camera (HRSC) experiment on Mars Express: Instrument aspects and experiment conduct from interplanetary cruise through the nominal mission. *Planetary and Space Science*. May 2007, 55, 7-8, pages 928–952. ISSN 00320633. doi: 10.1016/j.pss.2006.12.003. Available from: <http://linkinghub.elsevier.com/retrieve/pii/S0032063306003448>.
- [15] LOIZEAU, D. et al. Characterization of hydrated silicate-bearing outcrops in Tyrrhena Terra, Mars: Implications to the alteration history of Mars. *Icarus*. May 2012, 219, 1, pages 476–497. ISSN 00191035. doi: 10.1016/j.icarus.2012.03.017. Available from: <http://linkinghub.elsevier.com/retrieve/pii/S0019103512001108>.
- [16] MANGOLD, N. et al. Geomorphic study of fluvial landforms on the northern Valles Marineris plateau, Mars. *Journal of Geophysical Research*. August 2008, 113, E8, pages E08009. ISSN 0148-0227. doi: 10.1029/2007JE002985. Available from: <http://www.agu.org/pubs/crossref/2008/2007JE002985.shtml>.
- [17] MASSÉ, M. et al. Mineralogical composition, structure, morphology, and geological history of Aram Chaos crater fill on Mars derived from OMEGA Mars Express data. *Journal of Geophysical Research*. December 2008, 113, E12, pages E12006. ISSN 0148-0227. doi: 10.1029/2008JE003131. Available from: <http://www.agu.org/pubs/crossref/2008/2008JE003131.shtml>.

- [18] MONTMESSIN, F. et al. Hyperspectral imaging of convective CO<sub>2</sub> ice clouds in the equatorial mesosphere of Mars. *Journal of Geophysical Research*. November 2007, 112, E11, pages E11S90. ISSN 0148-0227. doi: 10.1029/2007JE002944. Available from: <http://www.agu.org/pubs/crossref/2007/2007JE002944.shtml>.
- [19] NEUKUM, G. *Amenthes Planum topography*. In *Space In Images* [online], 2013. [Accessed 03/21/2013]. Available from: [http://spaceinimages.esa.int/Images/2013/02/Amenthes\\_Planum\\_topography](http://spaceinimages.esa.int/Images/2013/02/Amenthes_Planum_topography).
- [20] PHILLIPS, R. J. et al. Mars north polar deposits: stratigraphy, age, and geodynamical response. *Science (New York, N.Y.)*. May 2008, 320, 5880, pages 1182–5. ISSN 1095-9203. doi: 10.1126/science.1157546. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/18483402>.
- [21] WILSON, A. (Ed.). *Mars Express: the scientific payload*. Noordwijk, Netherlands : ESA Publications Division, 2004. Available from: [www.esa.int/esapub/sp/sp1240/sp1240web.pdf](http://www.esa.int/esapub/sp/sp1240/sp1240web.pdf). ISBN 92-9092-556-6.



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