Mars atmospheric and surface spectroscopic diagnostics: Mars Express results and ExoMars update

O. Korablev[1]*

[1]*Space Research Institute (IKI), Moscow, Russia*

1. Introduction

Optical spectroscopy is one of the main, if not the primary, source of information about both the atmosphere and surface of Mars obtained remotely. Measurements are mostly performed in the optical spectral range of electromagnetic radiation, from the UV range 1000-2000 Å to the `thermal' infrared (IR) range 25-50 µm, from ground or space observatories, but mainly from spacecraft in orbits around Mars.

Spectral measurements started from the very beginning of spacecraft exploration of Mars. Earlier results we mostly related to the atmosphere: Mariner 6 and 7, Mars 2, 3, and 5 gave first data on the surface temperature, on the structure and composition of the atmosphere. Mariner 9 studied the seasonal cycle of ozone and water vapour. Viking orbiters monitored water vapour, thermal structure of the atmosphere, and surface temperature.

After a long gap in the spacecraft exploration of Mars, a brief Phobos 2 mission (1988-1989) gave some pioneering results, and implemented first the method of spectral surface mapping. Such studies are favored by the tenuous atmosphere of Mars. The surface best sensed in the range of reflected solar radiation (near- and mid-IR, 1-5 µm), which includes absorption bands of rock-forming minerals, clays, sedimentary rocks. Interpretation of the near-IR spectra is easier than in the thermal IR. As a spacecraft moves along the orbit, a surface image is constructed, each point corresponding to a spectrum.

Highly successful MGS with thermal emission spectrometer (TES) gave important hints about the surface composition, and monitored key atmospheric parameters during three Martian years. THEMIS, high-spatial-resolution radiometer on board Mars Odyssey performed global mapping of thermal inertia and led to several important conclusions about Martian geology. No trace of geothermal or volcanic activity (hot spots) has been found. The ESA Mars Express spacecraft launched in 2003 was equipped with three spectral instruments OMEGA, PFS and SPICAM, previously planned for unsuccessful Russian Mars 96 mission. Mars Reconnaissance Orbiter (MRO) carries CRISM mapping spectrometer and MCS limb radiometer. Spectral investigations of Mars after the Viking mission, with some selected references are listed in Table 1.

Mission	Instrument	Spectral range, µm	Spectral resolution	Spatial resolution	Main results
Phobos-2 1989	ISM-KRFM	0.315-0.6 0.8-3.1	30 nm 50 nm	20x30 km	Mineralogical mapping of a limited region; rock-forming minerals [1]
	Termoskan	0.6-0.95 8.5-12	- -	2 km	First mapping of thermal inertia [2]
	Auguste	0.22-0.43 0.76, 0.94 1.9, 3.7	10-30 nm - 2-3 nm	3-10 km limb	Vertical profiles of aerosol and water vapor [3, 4]
MGS 1997-2004	TES	5.8-50	6, 12 cm^{-1}	3 km	Global mapping; volcanic rocks, hematite locally found; no carbonates, clays, or sulfates found [5]. Monitoring of climate [6]
Mars Odyssey 2001-	THEMIS	0.45-0.85 6.5-15	5 bands 9 bands	100 m	Global mapping of thermal inertia [7]
Mars Express 2003-	OMEGA	0.35-1 1-2.5 2.5-5.1	7 nm 14 nm 20 nm	0.3-5 km	Global mineralogical mapping; hydrated minerals, clays, sulfides locally found [8]
	PFS	2-40	1.5 cm^{-1}	≥9 km	Discovery of methane in the atmosphere [9]
	SPICAM	0.118-0.32 0.9-1.7	1 nm 3.5 cm^{-1}	1x50 km 4 km	A number of atmospheric results [10]
MRO 2005-	CRISM	0.362-3.92	6.6 nm/pix	18 m	Detailed mapping, carbonates and serpentine locally found [11, 12]
	MCS	16.5-42.1	9 bands	5 km limb 1x1.7 km	Vertical structure of atmosphere and aerosols [13, 14]

Table 1: Spectral orbital spacecraft studies of Mars after Vikings.

2. Spectral mapping and the history of Mars's climate

The first global mineralogical mapping of Mars was performed by TES/MGS [5]. It revealed main rock-forming minerals: basalts typical for southern ancient highlands and andesites found in younger northern flatlands. The `wet' past of the planet was confirmed by local detections of hematite, a mineral formed in presence of water. No sedimentary rocks, carbonates, or the results of chemical erosion (clays) were detected, suggesting the cold dry climate dominated in the history of Mars. Also, no sulfates, indicative of volcanic activity, were found.

OMEGA at Mars Express revealed far more diversified surface and allowed making key conclusions about the history of Mars's climate. OMEGA data suggest that two widespread groups of hydrated minerals, phyllosilicates and sulfates, were formed during considerably different periods: clays at the early Noachian period, whereas sulfates, formed in an acidic and most likely dry environment, appeared later, 4-3.5 billion years ago [15]. Therefore, the 'early warm' period of Mars could have ended earlier than the 'classical' chronology based on geological estimates assumes. Later, Mars remained dry and its surface activity was very restricted, allowing slow oxidation and erosion to form the present-day appearance of the planet [8].

The enigma of carbonates on Mars was solved by CRISM/MRO thanks to its better spatial resolution [11]. Ancient carbonates, potentially burying the early atmosphere of Mars, are observed in very restricted regions, on valley slopes and meteorite craters.

3. Atmosphere and evidences of current activity

Spectral studies of the atmosphere are the main source of data for climate monitoring, and provide detection of minor atmospheric components, notably, those of possible volcanic or biological origin. The near and mid-IR regions are good for measuring many minor constituents, which are detected at high spectral resolution. Upper atmosphere, excited molecular states, and some gases, are studied in the UV, water vapour in the near-IR, and, a 15 μm CO_2 band can be inverted to estimate temperature profile from the surface up to 40-60 km. PFS and SPICAM, two versatile spectrometers on board Mars Express are mainly used to investigate the atmosphere and climate of the planet. Among their multiple results [Giuranna, Montmessin] the discovery of methane revived hopes of Mars still being an active planet from a geological or biological perspective. In fact the detection of methane was first reported in three nearly simultaneous pioneering works [9, 16, 17], but astronomical observations and their analysis were undoubtedly stimulated by the PFS measurements.

The putative presence of methane promoted detailed studies of the Martian atmosphere and climate, identified as the primary scientific goal of the ExoMars Trace Gas Orbiter (TGO) [18]. TGO, now in aerobraking phase carries a powerful set of atmospheric instruments, ACS and NOMAD, to establish a detailed inventory of the trace gases existing in the Martian atmosphere [19, 20].

4. References

[1] Bibring, J.-P. et al. Nature , Vol. 341, pp. 591-593, 1989.
[2] Moroz, V.I., Petrova, E.V., Ksanfomality, L.V. Planet. Space Sci., Vol. 41, 569, 1993.
[3] Blamont, J.E. et al. Planet. Space Sci., Vol. 39, pp. 175-187, 1991.
[4] Rodin, A.V., Korablev, O.I., and Moroz, V.I. Icarus, Vol. 125, pp. 212-229, 1997.
[5] Christensen PR et al. J. Geophys. Res. Planets Vol. 106, pp. 23823-23872, 2001.
[6] Smith, M.D. Icarus, Vol. 167, pp.148-165, 2004.
[7] Christensen, P.R. et al. Science, Vol. 300, pp. 2056-2061, 2003.
[8] Bibring, J.-P. et al. Science, Vol. 312, pp. 400-404, 2006.
[9] Formisano, V. et al. Science, Vol. 306, pp. 1758-1761, 2004.
[10] Montmessin, F. et al. Icarus, Vol. 297, pp. 195-216, 2017.
[11] Murchie, S. et al. J. Geophys. Res. Planets, Vol. 112, pp. E05S03, 2007.
[12] Ehlmann, B.L., Mustard, J.F., and Murchie, S.L. Geophys. Res. Lett., Vol. 37, pp. L06201, 2010.
[13] McCleese, D.J. et al. J. Geophys. Res. Planets, Vol. 112, pp. E05S06, 2007.
[14] Heavens, N.G. et al. J. Geophys. Res. Planets, Vol. 116, pp. E04003, 2011.
[15] Poulet, F. et al. Nature, Vol. 438, pp. 623-627, 2005.
[16] Krasnopolsky, V.A., Maillard, J.P. and Owen, T.C. Icarus, Vol. 172, pp. 537-547, 2004.
[17] Mumma, M.J. et al. Science, Vol. 323, pp. 1041-1045, 2009.
[18] Zurek, R.W. et al. Planet. Space Sci., Vol. 59, pp. 284-291, 2011.
[19] Korablev, O.I. et al. Space Sci. Rev, submitted.
[20] Vandaele, A.-C. et al. Space Sci. Rev, submitted.

Short Summary

Spectroscopic diagnostics and mapping is a primary source of information about the atmosphere and surface of Mars obtained remotely. The spacecraft spectral investigation will be reviewed with an emphasis on Mars Express results and ExoMars expected capabilities.