THE ORBITAL PRESPECTIVE: HOW OUR WORLD VIEW HAS CHANGED. W. M. Calvin[1], [1]University of Nevada, Reno, Geological Science, MS 172, Reno, NV 89557, wcalvin@unr.edu

Introduction: The first infrared spectrometer to record observations of the Martian surface from a spacecraft were the Mariner 6 and 7 IRS instruments on a flyby in August of 1969 [1]. Mariner 9 (1971) orbited the planet and the IRIS instrument mostly recoded atmospheric properties due to the large planet encircling dust event [2]. While multi-spectral imagers acquired data from Viking, the next spectrally resolved instrument did not arrive until the French instrument ISM on the Russian Phobos spacecraft in 1989 [3]. Calvin and Bell (2008) [4] summarized the general state of knowledge prior to the arrival of Mars Global Surveyor. With the advent of the modern exploration era, TES, OMEGA and CRISM have revolutionized our understanding of the surface mineralogical composition providing global maps and high resolution detail of rover landing sites [e.g. 5,6,7,8] and detailed examination of seasonal polar processes [e.g. 9,10,11,12].

This history focusses on what were the game changing observations and discoveries made from these spectrometers and how they paved the way for the next steps in our current understanding of Martian surface composition. I also consider what crucial data are missing or could advance our understanding in significantly new ways based on developments in laboratory spectroscopy at micrometer scales.

Instrument Summary: Table 1 provides information for the spacecraft instruments discussed including wavelength range, spectral resolution, best spatial footprint, and spatial coverage.

Mariner 6/7 IRS: The two profound results from these instruments were the observation of solid CO_2 in the seasonal south cap [1] and longer wavelength information (at 3-µm) identified as bound water [13]. Recovery of the data and modern calibration allowed identification of spatial variability in the bound water content [14] and water ice enrichment at the edge of the retreating south seasonal CO_2 cap as well as strong spatial variation in the ice features that were consistent with very long pathlengths in ice [15].

Mariner 9 IRIS: The majority of IRIS data was collected during a strong atmospheric dust event. However early work clearly identified the silicate nature of the dust [2]. Christensen [16] used Viking IRTM data coupled with the few IRIS spectra collected during the daytime after the dust storm abated to identify spatially variable patterns in surface emissivity that was used to motivate the TES instrument. These data were consistent with a mafic to ultramafic surface but identified that unweathered feldspars were likely to be significant components of the surface mineralogy.

ISM: The major results from ISM focused on the nature of the mafic minerals, identifying both low- and high calcium pyroxenes (LCP and HCP) [e.g. 17, 18] and mixing of mafic materials with bright dust as a significant cause of spectral variability. Murchie et al. [18] also identified dark red soils as a distinct spectral unit and noted variation in the bound water signature.

TES/Mini-TES: Although the spatial resolution of the TES instrument is coarse, the instrument provided the first global maps of composition and major discoveries of coarse-grained gray hematite, abundant olivine, carbonate in the globally distributed dust [5,19,20,21]. The global mapping also identified two primary mafic surface types, differing primarily in silica content [5] which is likely caused by weathering [e.g. 7].

TES also made breakthrough discoveries with regard to polar volatiles identifying locations in the seasonal cap that are cold, but dark and were thus dubbed "cryptic" now widely accepted to be slab CO_2 ice that anneals during the winter [9].

The TES orbital data were ground-truthed on the surface with the Mini-TES instruments on the twin MER rovers. The Meridiani landing site was selected based on the orbital geochemical signature of hematite which was found to be in small spherules eroding from sulfate outcrop [22,23]. New discoveries also included extremely high-silica material and carbonate in country rock at the Spirit site [24,25].

OMEGA: Although the elliptical orbit of Mars Express limited the highest spatial resolution data to 300m, OMEGA early on identified hydrated sulfates in several locations as well as phyllosilicate minerals [26,27] and these were in distinct geologic terrains leading to an age related alteration scenario [28]. Ultimately, global maps of mafic mineralogy as well as bound water distribution were produced [28, 29].

With regard to polar volatiles, OMEGA crucially showed that the cryptic terrain does not retain the signature of CO_2 ice, that the ice grain size of the northern residual ice varies over the summer season, and that the retreating north seasonal cap is a complex mixture of both water and CO_2 frosts [30,31,9]. Spectral mapping of residual ice in the south shows a complex admixture of water, CO_2 and dust [32].

CRISM: It is not hyperbole to say that the high spatial resolution of CRISM has revolutionized our understanding of the surface composition of Mars. Coupled with high resolution imagery from HiRISE and CTX we have an unprecedented ability to determine the mineralogical nature of units and their geologic associations. CRISM has found incredible diversity of mineralogy including, a wide array of phyllosilicates, carbonate, alunite and other sulfates, zeolites, prehnite and opaline silica. [summarized in 6,7]. These alteration minerals occur in extremely diverse environments [33] with a wide range of possible formation mechanisms including surface weathering, hydrothermal systems around impact craters or volcanoes, and subsurface alteration in groundwater. CRISM data has been pivotal in identifying high priority landing sites for MSL, ExoMars, and the 2020 rover.

With regard to polar processes, CRISM showed the dark material of the PLD is still ice rich and provided a new way to view composition and ice cemented soils of the layered terrain in the northern PLD [34]. Detailed analysis of CRISM data over south polar residual ices and the varying geomorphic textures is just beginning under a newly funded MDAP award.

Critical Gaps: In spite of the wealth of orbital data at reflected solar wavelengths, we still have not made spectral measurements on the ground in wavelengths from 1 to 5 µm. Comparing CRISM pixels to mineralogy from ChemMin is truly an apples to oranges approach. However, Supercam on Mars 2020 will cover some of this wavelength range with point spectra.

The Future: While our landed assets have shown that mineralogy is often observed in-situ and not well resolved from orbit, the converse however is more true. Where spectral signatures from orbit are strong and unequivocal the surface evidence will be unmistakable. The next step is to bring infrared spectroscopy down to the scale of the microscopic imager or petrographic microscope scale. This technology is available in terrestrial labs now and can rapidly provide identification of minerals not simply elemental composition. Such instruments have been proposed for rovers and landers and could significantly enhance future mission science return.

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Table 1: Mars Spacecraft Infrared Spectrometers

Spacecraft	Year	Instrument	Wavelength range in µm	Spectral Resolution	Best Spatial Footprint	Spatial Coverage
Mariner 6, 7	1969	IRS	1.9 to 14.4	1-2%	200 km	4 strips, ~ 60 spectra of the surface
Mariner 9	1971	IRIS	5 to 50	2.4 cm^{-1}	126 km	~85 of 21,000 spectra are daytime, no dust
Phobos-2	1989	ISM	0.76 to 3.1	40 nm	22 km	Six large swaths over Valles Marineris, Syrtis, Meridiani and Ascraeus to Lunae Planum.
MGS	1998	TES	6 to 50	10 cm^{-1}	3 x 6 km	Global
Mars Express	2004	OMEGA	0.35 to 5.1	14 nm	300 m	Global
Mars Express	2004	PFS	1.2 to 45	1.3 cm^{-1}	12 km	Primarily atmospheric oriented
MRO	2006	CRISM	0.36 to 3.9	6.55 nm	18 m	Global at 200 m/ pixel. Few % at highest res.
MER	2004	Mini-TES	5 to 29	10 cm^{-1}	~ 15cm	Selected locations at the landing sites