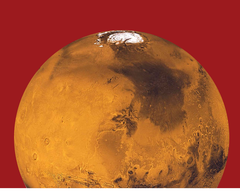
50 Years of Mass Spectrometry at Mars

Phillip C. Price, ASMS History Committee



Background

Over the last 50 years, only nine mass spectrometers have successfully operated at Mars -

- Three orbiters
- Two atmosphere entry vehicles
- Three surface landers
- One surface rover

This presentation provides historical context for past instrumentation, to better appreciate future Mars missions.

Why So few?

Getting an undamaged instrument to Mars is difficult -

One year of travel time with temperature and radiation (~0.4 Sv/yr) extremes
Velocity at Mars approach = 14,400-25,200 kph
Landing velocity must be < 9 kph
Mars gravity is 37.6% Earth's – sufficient to smash spacecraft
Mars atmosphere (610 Pa vs Earth's 101,325 Pa) – dense enough to require entry shields, so thin that conventional parachute braking is difficult
Mars is typically 4.2-20.8 light-minutes from Earth; spacecraft must be highly autonomous.

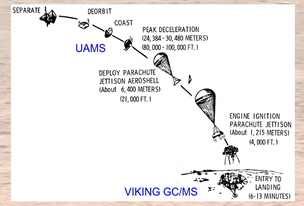
Future Prospects

Based on current planning and construction, several countries are preparing for much more sophisticated MS instrumentation at Mars. Using typical "Hohmann transfer" trajectories, the next likely launches would be Summer of 2022 and Fall of 2024 and 2026. Ballistic capture or Aerocapture trajectories would have more flexible timelines, but have never been attempted at Mars.

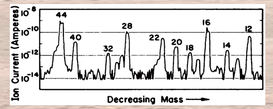
Name	Launch	Arrival	Mission	Operation	Instrument Mass (kg)	Dimensions (cm)	Instrument Volume (L)	Total Watts	Analyzer Type	Scan Range (Da)	Scan Rate (sec)	Calibration	Sensitivity	Dynamic Range	Detector Type	Ionization	Pumping System(s)	GC columns	Computer System – CPU, Storage	Data Transmission to Earth
Viking 1 Aeroshell UAMS	20-Aug-75	20-Jul-76	200-120 km Altitude during 4.5 kps Entry	Minutes (per design)	6.2	24 x 30 x 24	17.5	13.3	Mattauch-Herzog	1-49	5	Raw Data Interp @ JPL, Univ. of MN	1e-7 A/Pa N_2	1.E+05	2 Faraday Cups m/z 1-7, 7-49	Single Filament, EI 75 & 25 eV	not required	no GC	Links to Earth, Oorbiter & Lander recorders	20-30 MB/day - Orbiter
Viking 1 Lander GC/MS	20-Aug-75	20-Jul-76	Lander; 29 km off target	Analyses on 22 Sols over 3 months	19	28 x 30 x 38	32	25-140	Reverse Nier-Johnson 90°/90°	12-215	10	Raw Data Interp @ MIT	3e-8 A/Pa N_2; 100 ppm N_2 @ S/N=4	1.E+07	12-stage Venetian Blind Cu/Be EM	Dual Ffilament EI; 40 & 70 eV	Ion Pump, 0.5L/sec; 0.25 watts	Poly MPE-Tenax, 2m x 0.75mm	196 KB CPU + 40 MB Wire Recorder	20-30 MB/day - Orbiter; 1MB/day - Lander
Viking 2 Aeroshell UAMS	9-Sep-75	3-Sep-76	200-115 km Altitude during 4.5 kps Entry	Minutes (per design)	6.2	24 x 30 x 24	17.5	13.3	Mattauch-Herzog	1-49	5	Raw Data Interp @ JPL, Univ. of MN	1e-7 A/Pa N2	1.E+05	2 Faraday Cups m/z 1-7, 7-49	Single Filament, EI 75 & 25 eV	not required	no GC	Links to Earth, Orbiter & Lander Recorders	20-30 MB/day - Orbiter
Viking 2 Lander GC/MS	9-Sep-75	3-Sep-76	Lander; 6 km off target	Analyses on 26 Sols over 2 months	19	28 x 30 x 38	32	25-140	Reverse Nier-Johnson 90°/90°	12-215	10	Raw Data Interp @ MIT	3e-8A/Pa N2; 100 ppm N2 @ S/N=4	1.E+07	12-stage Venetian Blind Cu/Be EM	Dual Filament EI; 40 & 70eV	Ion Pump, 0.5L/sec; 0.25 watts	Poly MPE-Tenax, 2m x 0.75mm	196 KB CPU + 40 MB Wire Recorder	20-30 MB/day - Orbiter; 1MB/day Lander
Phoenix, TEGA	4-Aug-07	25-May-08	Lander; 7 km off target	May - Nov 2008	5.7	24 x 23 x 18	10	13	Permanent magnetic sector	1-140	1.6	CO_2, H_2O, O_2	10 ppb	2.E+07	4 EMs m/z 0.7-4, 7-35, 14-70, 28-140	Dual Filament EI; 23, 27, 37, & 90 eV	Ion Pump, 1L/sec	no GC; DSC/MS	74 MB CPU + 112 MB Aux	32 kbps; 50 MB/day
Curiosity, SAM	26-Nov-11	6-Aug-12	Rover; 2.4 km off target; 24 km of travel	Nov 9, 2012 - 2013, ~125 Sols	40	40 x 40 x 30 (est.)	50	150	Quad MS	2-535	1-100	Fluoronaphthalene, Fluorophenanthrene, PFTBA	CH_4: 2 ppb; H_2O 2 ppm; 100x less after enrich	1.E+09	EM, Pulse Count	Dual Filament EI; 70eV	Dual Turbo Pumps	30 x 0.25mm, 6 columns+TCD	250 MB CPU, 2 GB Aux	250 MB/day, via Orbiter relay
Mangalyaan Mars Orbiter Mission, MENCA	5-Nov-13	24-Sep-14	Orbiter; 265-71,000 km altitude	Sep 29, 2014 - ?	4	----------	<5 (est.)	29	Quad MS	1-300	19-540	----------	7e-14 Pa	1.E+10	Faraday Cup & EM	Dual Filament EI; 70eV	not required	no GC	----------	----------
Maven, NGIMS	18-Nov-13	22-Sep-14	Orbiter; 125-6,200 km (data 125-500) altitude	Sep 2014 - present	14	41 x 40 x 22	36	40	Quad MS	2-150	1-3.5	N_2, CO_2, Ar, Kr, Xe @4e-5 Pa	Ar: ~3e-2 (cts/sec)/(part/cc)	1.E+08	Dual CEMs, G=5e7	Dual 75eV open/closed EI sources	not required	no GC	3 MB RAM + EEPROM	2 MB/sec
Tianwen, MINPA	23-Jul-20	10-Feb-21	Orbiter; MINPA powered on, testing		3.1	----------	<5 (est.)	8.4	TOF; similar to STATIC on MAVEN	1-70	4	High-Energy particles, Switzerland, China	----------	----------	MCP	C-E Plate; 25 mm Al_2O_3 on Si	not required	no GC	----------	----------

Timeline for Successful Mass Spec Launches

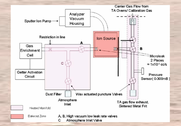
- 1975 Viking entry vehicle, lander
- 2007 Phoenix lander
- 2011 Curiosity rover
- 2013 Maven, MOM orbiters
- 2020 Tianwen orbiter
- 2025 ASMS Baltimore



Viking Mars Approach – MSs on Aeorshell & Lander[1]

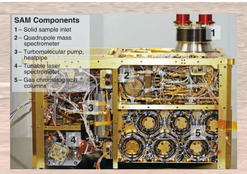


First MS from Mars[3], July 20, 1976
Altitude = 135km, T = -175°C

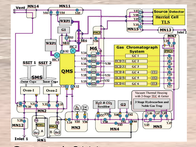


Phoenix TEGA – Mass Spectrometer & Thermal Analyzer Inlet[11]

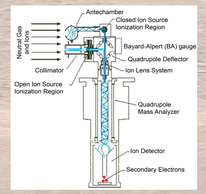
Water Ice Sublimating in Bottom of Phoenix-Dug Sample Trench[12]



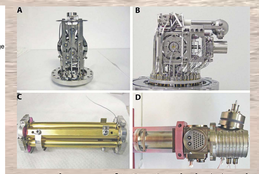
Curiosity's SAM Quadrupole GC/MS[13]



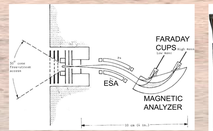
Curiosity's SAM Quadrupole GC/MS – Inlets & Sampling[14]



MAVEN's NGIMS, Ion and Gas Flow[21]

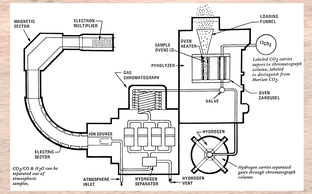


Major Elements of NGIMS include (A) redundant detectors, (B) dual ion source, (C) quadrupole rods (D) sensor housing and ion source flanged cover with metal-ceramic-metal breakoff cap deployed at Mars[21]

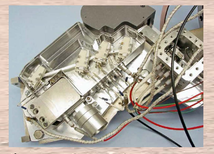


Nier UAMS Instrument, Mounted on Viking Aeroshell[2]

Viking GC/MS[4] – Packaged for Launch



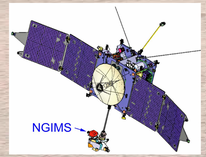
Viking GC/MS Components[5]



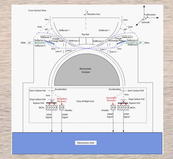
Phoenix TEGA Mass Spectrometer, Ion Source & 4 Electron Multipliers[11]

Curiosity Rover in Spacecraft Assembly Facility at JPL[15]

MENCA; Electronics & Telemetry Box[20]



Instrument Pod on Articulated Arm below MAVEN[21]



Tianwen's MINPA, Trajectories of ions, ENAs, and secondary electrons[25]

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