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## **Mature Mass Spectrometry Technologies for Resource-Limited Missions**

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NASA's Goddard Space Flight Center (GSFC) has been developing quadrupole mass spectrometers (QMS) for planetary exploration since the Pioneer Venus Program in the 1970s. Following Pioneer, QMS-based instruments delivered by GSFC have been flown to Saturn (on both the Cassini orbiter and Huygens descent probe at Titan), Mars (MSL and MAVEN) and the Moon (LADEE). Our understanding of the Solar System has thus been augmented significantly by these instruments, which are low risk and cost efficient due to their technical maturity and demonstrated performance. In order to enhance the capabilities of these heritage-based systems and enable other mass spectrometry approaches, GSFC has been pursuing new, cutting-edge technologies. Examples include: atmospheric ion inlet systems (e.g., for ion transport at elevated pressures); highly efficient and tunable laser sources of various wavelengths and power outputs (e.g., for laser desorption/ionization of rock samples); high-temperature pyrolysis ovens that enable the breakdown of refractory minerals and the release of noble gases (e.g., for evolved gas analysis and in situ geochronology); and, capture and enrichment techniques for analysis of volatiles, aerosols and dust particles (e.g., for a comet rendezvous or flyby of an airless body).

Recently, we have developed a set of advanced analytical capabilities associated with alternative mass analyzers. The mass spectrometer subsystem of the Mars Organic Molecule Analyzer (MOMA), part of the ExoMars 2018 rover payload, detects trace organics in solid samples via pyrolysis/gas chromatography (pyr/GC) with a tunable electron ionization sources, as well as pulsed UV laser desorption/ionization (LDI) at Mars ambient pressure. The core of the MOMA instrument, a two-dimensional ion trap, facilitates both selective ion enrichment via stored waveform inverse Fourier transform (SWIFT) techniques, and tandem mass spectrometry (MSn). Expanding upon the MOMA platform, a next-generation Linear Ion Trap Mass Spectrometer (LITMS), capable of negative ion detection, solid core sampling and an extended mass range, is also under development.

Our time-of-flight (TOF) mass spectrometers have been interfaced to a range of laser sources to advance capabilities for high-sensitivity laser ablation and desorption methods for analysis of inorganic signatures and non-volatile organic compounds, respectively. Prompt ionization at UV (commonly 266 or 355 nm) and NIR (1064 nm) wavelengths allows for a broad survey of organics embedded in geological samples, and at higher fluences the mineral host of the organics may be more easily analyzed. Laser processing of organically-rich icy matrices has also been shown effective, albeit at longer wavelengths between 2700 – 3100 nm. For the selective ionization of specific classes of

organics, such as polycyclic aromatic hydrocarbon (PAHs) and aromatic heterocycles, two lasers may be employed to decouple the desorption and ionization steps and limit molecular fragmentation. Mass analyzers with intrinsically higher resolving powers ( $m/dm > 100,000$ ), such as the Orbitrap-based AROMA instrument under development, offer the potential to disambiguate key chemical signatures in complex mass spectra. Moreover, GCs like those flown on Cassini-Huygens and MSL, and other chromatographic techniques, offer complementary capabilities to discern competing mass signals at only a minor increase in cost due to successfully demonstrated and qualified heritage designs.