EMIRATES MARS MISSION (EMM) OVERVIEW

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Introduction:

United Arab Emirates (UAE) has entered the space exploration race with the announcement of Emirates Mars Mission (EMM), in July 2014. Through this mission, UAE is to send an unmanned probe, called Hope probe, to Mars by 2021 to coincide with UAE's 50th anniversary. UAE President, His Highness Sheikh Khalifa bin Zayed Al Nahyan, has highlighted that EMM is a strategic initiative and a turning point in the UAE's development as it establishes the space technology sector as a key component of the national economy, it advances the Science and Technology Sector in the UAE, it develops UAE scientific capabilities, and it increases UAE's contribution to the international scientific community. The mission is led by Emiratis from Mohammed Bin Rashid Space Centre and it will expand the nation's human capital through knowledge transfer programs set with international partners from the University of Colorado/Laboratory for Atmospheric and Space Physics (LASP), University of California Berkeley Space Sciences Lab (SSL), and Arizona State University (ASU) School of Earth and Space Exploration.

Science Motivation and Overview:

Our understanding of Mars' atmosphere has been significantly limited by the fixed local time of recent measurements made by several spacecraft, leaving most of the Mars diurnal (i.e. day-to-night) cycle unexplored over much of the planet. Thus important information about how atmospheric processes drive diurnal variations is missing. This limited coverage has hindered our understanding of the transfer of energy from the lower-middle atmosphere to the upper atmosphere. EMM will be able to observe and investigate the Mars lower and upper atmosphere simultaneously, enabled by a high altitude orbit and synoptic perspective. Views of most of the planet's surface at most times of day will enable unprecedented studies of the physical processes that drive the global atmospheric circulation, temperature structure, and the distribution and interaction of ice clouds, water vapor and dust (which can shroud the surface in spectacular storms). In addition, EMM will reveal the connection between these conditions in the lower atmosphere and the escape of hydrogen and oxygen from the upper atmosphere, a process that may have been responsible for Mars' transition, over billions of years, from a thick atmosphere capable of sustaining liquid water on the surface, to the cold, thin, arid atmosphere we see today.

Science Objectives and Investigations:

The Martian atmospheric science issues discussed can be distilled to three motivating science questions leading to three associated objectives summarized in Table 1.

Table 1: EMM Motivating Science Questions and Objectives

Motivating Questions		EMM Science Objectives
How does the Martian lower atmosphere respond globally, diurnally and seasonally to solar forcing?	→	A. Characterize the state of the Martian lower atmosphere on global scales and its geographic, diurnal and seasonal variability
How do conditions throughout the Martian atmosphere affect rates of atmospheric escape?	→	B. Correlate rates of thermal and photochemical atmospheric escape with conditions in the collisional Martian atmosphere.
How do key constituents in the Martian exosphere behave temporally and spatially?	→	C. Characterize the spatial structure and variability of key constituents in the Martian exosphere.

While objective A focuses on understanding the Martian lower atmosphere, objective C concentrates on characterizing the Martian exosphere. Objective B is uniquely developed to correlate the lower atmospheric processes and conditions with atmospheric escapes in the exosphere through the thermosphere. EMM will achieve these three objectives through four specific, focused science investigations. All four investigations require atmospheric variability to be determined on sub-seasonal timescales, to enable understanding of the effects of heliocentric distance variation and planetary obliquity on dynamical processes in all regions of the atmosphere. The correspondence between the mission objectives and investigations are shown in Table 2.

Table 2: EMM Science Objectives and Investigations

EMM Science Objectives	EMM Science Investigations
A. Characterize the state of the Martian lower atmosphere on global scales and its geographic, diurnal and seasonal variability	1. Determine the three-dimensional thermal state of the lower atmosphere and its diurnal variability on sub-seasonal timescales.
B. Correlate rates of thermal and photochemical atmospheric escape with conditions in the collisional Martian atmosphere.	2. Determine the geographic and diurnal distribution of key constituents in the lower atmosphere on sub-seasonal timescales.
	3. Determine the abundance and spatial variability of key neutral species in the thermosphere on sub-seasonal timescales.
C. Characterize the spatial structure and variability of key constituents in the Martian exosphere.	4. Determine the three-dimensional structure and variability of key species in the exosphere and their variability on sub-seasonal timescales.

Investigation 1. Investigation 1 will determine the three-dimensional thermal state of the lower atmosphere and its diurnal variability on sub-seasonal timescales. During this investigation, EMM will measure vertical temperature profiles from the surface to an altitude up to 50 km. Along with Investigation 2, EMM will sample the Martian lower atmosphere on sufficient spatial and temporal scales to elucidate the processes driving global circulation in the current Martian climate. To satisfy this investigation, the physical parameters needed are the atmospheric temperature profiles, measured through the absolute radiance of the CO2 absorption band, and the surface temperature of Mars, measured through the absolute radiance over a subset of the spectral range.

Investigation 2. Investigation 2 will determine the geographic and diurnal distribution of key constituents in the lower atmosphere on sub-seasonal timescales. To complete this investigation and to better understand the processes that are driving the global circulation in the current Martian climate, EMM will sample the key constituents (ozone, water vapor, water ice and dust) that are present in the lower atmosphere on sufficient spatial and temporal scales to (along with investigation 1), usefully constrain current state-of-the-art models of the atmospheric circulation. To satisfy this investigation, the physical parameters needed are the ice optical depth (at 12 µm and 320 nm), dust optical depth (at 9 µm and 220 nm), ozone column abundance (at 245 – 275 nm), water vapor abundance (at 25 – 40 µm), and the surface temperature of Mars.

Investigation 3. Investigation 3 will determine the abundance and spatial variability of key neutral species in the thermosphere on sub-seasonal timescales. During this investigation, EMM will provide a measure of the dynamics and energetics of the thermosphere, through which all escaping particles must travel, as it forms the lower boundary of the exosphere. This will be done through determining the column abundance and spatial variability of the key neutral species: oxygen, carbon, and carbon monoxide in the thermosphere. To satisfy this investigation, the physical parameters needed are the column densities of oxygen (130.4nm & 135.6nm), carbon (156.1nm & 165.7nm), and carbon monoxide (CO 4PG: 140–170nm) in the thermosphere with a relative accuracy (between species) of 30% and a spatial resolution of less or equal to 300 km at nadir (i.e. the resolution of global 3-D atmospheric models). These species are expected to vary in a timescale of ~1 day and their impact on the exosphere is expected in a timescale of ~1 week.

Investigation 4. Investigation 4 will determine the three-dimensional structure and variability of key species in the exosphere and their variability on sub-seasonal timescales. This investigation is since it is focused on the exosphere, the channel through which Mars' atmosphere escapes to space. During this investigation, EMM will determine the three-dimensional structure and temporal variability of the neutral exosphere species hydrogen and oxygen through far ultraviolet measurements made from multiple viewing angles on a weekly cadence or better. Rates of hydrogen escape can be derived by EMM ability to measure optically-thin Lyman beta (102.6 nm) hydrogen emission up to 1.6 Mars radii, allowing intensities to be converted directly to column densities and thereby better constraining three dimensional representations of the exosphere. Further, EMM will periodically measure Lyman Alpha emission up to 10 Mars radii, where it becomes optically thin and where the hot, escaping component of the velocity distribution can be better separated from the colder, bound component. On the other hand, Mars' atomic oxygen corona results almost entirely from dissociative recombination of molecular oxygen ions (the most abundant in the thermosphere/ionosphere). This exothermic photochemical reaction results in fast neutral oxygen atoms with a range of energies up to ~3.6 eV. Those that escape the collisional atmosphere and reach the near-collisionless exosphere can be divided into 2 different categories: those with greater than and less than escape velocity (2 eV). Observations of the OI 130.4 nm FUV emission from 200 km altitude out to several Mars radii will allow these two populations to be separated and hence enable the determination of the rate of photochemical escape of atomic oxygen.

Thus, to satisfy investigation 4, the physical parameters needed are the densities of both hydrogen and oxygen in the Martian exosphere. The expected spatial scale of exospheric variability can be of thousands of kilometers with a timescale of variability of ~ 1 week.

Instruments Overview:

EMM will collect information about the Mars atmospheric circulation and connections through a combination of three distinct instruments that image Mars in the visible, thermal infrared and ultraviolet wavelengths and they are the Emirates eXploration Imager (EXI), the Emirates Mars InfraRed Spectrometer (EMIRS), and the EMM Mars Ultraviolet Spectrometer (EMUS). A summary of the three instruments is in Table 3.

Table 3: EMM Payload

Payload	EXI	EMIRS	EMUS
Capability	Ultraviolet-Visible camera	Fourier transform infrared spectrometer	Ultraviolet imaging spectrograph
Supplier	LASP & MBRSC	ASU & MBRSC	LASP & MBRSC
Spectral Range	205-235nm 245-275nm 305-335nm 405-469nm 506-586nm 620-650nm	6 – 40 microns	100 – 170 nm

The primary science goal of EXI is to measure the optical depths of dust and water ice in the Martian atmosphere at 220 nm and 320 nm, respectively, as well as the column abundance of ozone. In contrast, EMIRS will measure the global distribution of key atmospheric parameters over the Martian diurnal cycle and year, including dust, water ice (clouds), water vapor and temperature profiles. In doing this, it will also provide the linkages from the lower to the upper atmosphere in conjunction with EMUS and EXI. As for EMUS, it is designed to measure relative changes in the thermosphere and the structure – radial extent and scale height – of both the hydrogen and oxygen exospheres. Additionally, it will measure changes in the structure of the corona with season, solar inputs, and lower atmosphere forcing (e.g. dust storms). Measurements of both hydrogen and oxygen in the upper atmosphere are essential for determining the loss of water from the upper atmosphere.

Spacecraft Overview:

The EMM spacecraft, named Hope, is the combination of the instrument suite and spacecraft bus. The spacecraft launch mass is estimated at 1500kg with a primary structure consisting of aluminum panels with aluminum facesheets. While in space, Hope will operate using solar arrays and batteries and will communicate with ground antennas using 1.5m diameter high gain antenna. It has as well a Small Deep Space Transponder that performs uplink and downlink of data and supports deep space tracking for navigation purposes. For attitude determination, it has a redundant pair of 3-axis inertial reference units and a redundant pair of star trackers. For attitude control, it will have a set of 4 reaction wheels, as well as Reaction Control System thrusters for momentum dumping.

Mission Timeline, Operation and Lifetime:

EMM design, development and testing phase extends from mid-2014 to mid-2020 for a total of 6 years before launch takes place in summer 2020. Figure 1 summarize the mission timeline.

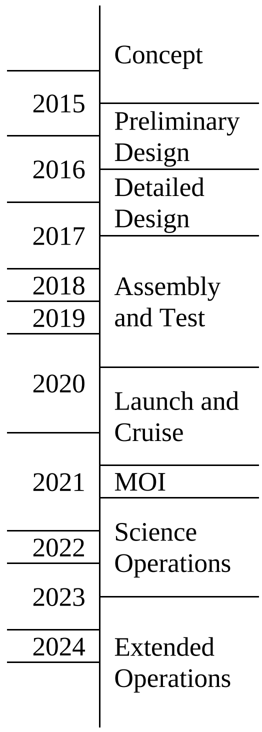

Figure 1: EMM Timeline

The EMM operational life consists of the Cruise Phase that follows launch and it will be limited to instrument checkout and calibration activities. Following Mars orbit insertion, the Capture Orbit phase is characterized by a highly elliptical 35-hour orbit (500 km periapsis, 44,500 km apoapsis) from which all three instruments will be checked out and their science sequences tested, resulting in early observations of the Mars disc and upper atmosphere. This phase will be completed in less than three months without requiring any subsequent spacecraft maneuvers or deployments. Following this, a Transition Orbit phase will be characterized by the gradual enlargement of the orbit over the course of ~1 month until it is optimized (20,000 km x 43,000 km) for science data collection. Finally, the Primary Science phase will begin and is expected to last 2 Earth years. EMM is designed for an additional 2 year extended science mission in the same orbit as the primary science mission, see Figure 2.

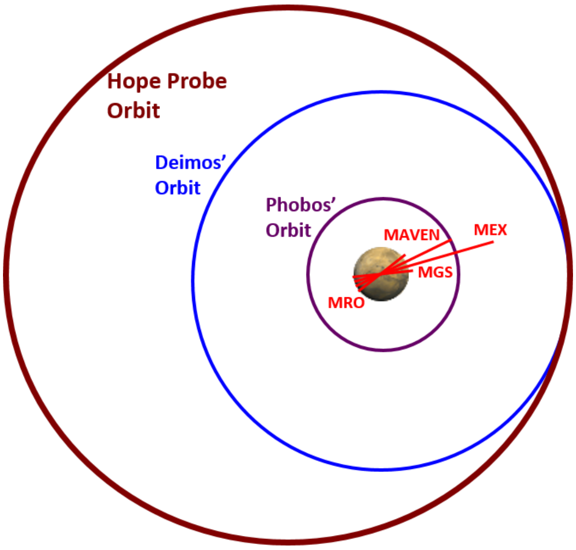

Figure 2: EMM Target Science Orbit

The 20,000 km periapsis altitude during the Primary Science phase is sufficient to ensure global-scale, near-hemispheric views throughout the orbit and to allow daily coverage of all longitudes and local times. The orbital period will be approximately 55 hours. Over the course of ~2 Earth years, this will enable a comprehensive characterization of Mars' lower atmosphere variability as a function of location, time of day, and season, as well as an understanding of how physical processes in the lower atmosphere affect the rates of escape from the exosphere.

Summary:

The Emirates Mars Mission (EMM) will explore the dynamics in the atmosphere of Mars on a global scale while sampling contemporaneously both diurnal and seasonal timescales. Using three science instruments on an orbiting spacecraft, EMM will provide a set of measurements fundamental to an improved understanding of circulation and weather in the Martian lower and middle atmosphere. Combining such data with the monitoring of the upper layers of the atmosphere, EMM measurements will reveal the mechanisms behind the upward transport of energy and particles and the subsequent escape of atmospheric particles from the gravity of Mars. The unique combination of instrumental synergy and temporal and spatial coverage of Mars' different atmospheric layers will open a new and much-needed window into the workings of the atmosphere of our planetary neighbor.