EMIRATES MARS MISSION 2020: SCIENCE TARGETS AND OBSERVATIONS

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Introduction: The United Arab Emirates (UAE) entered the space exploration race with the announcement of Emirates Mars Mission (EMM) in July 2014. EMM is considered to be the first Arab Islamic mission to another planet. This mission will send an unmanned probe, called “Hope”, to Mars by 2021 coinciding with UAE’s 50th anniversary. The president of the UAE, His Highness Sheikh Khalifa bin Zayed Al Nahyan 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 the UAE’s scientific capabilities, and it increases the UAE’s contribution to the international scientific community. The mission is led by Emiratis from Mohammed Bin Rashid Space Centre (MBRSC) 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 (CU/LASP), University of California Berkeley Space Sciences Laboratory (UCB/SSL), and Arizona State University School of Earth and Space Exploration (ASU/SESE). [1] (Sharaf, Amiri et al, 2017)

Science Motivation and Overview: Mars has long been the interest of many scientists around the globe. Several missions to Mars have helped in unlocking key information to the understanding of the processes and cycles of Mars’ atmosphere. However, a large fraction of the recently acquired observations of Mars have been obtained from spacecraft in sun-synchronous orbits (i.e., providing a limited range of local times), leaving much of the Mars diurnal cycle unexplored. This limited coverage has limited our understanding the transfer of energy and matter within the lower-middle atmosphere and exchange with. 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. [1] (Sharaf, Amiri et al., 2017).

Science Objectives and Investigations: The Martian atmospheric science issues discussed can be distilled into three motivating science questions leading to three associated objectives that are aligned with MEPAG Goal II: “Understand the processes and history of climate on Mars” 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 on dynamical processes in all regions of the atmosphere. The correspondence between the mission objectives and investigations are shown in Table 2. (Sharaf, Amiri et al., 2017)

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 is to determine the three-dimensional thermal state of the lower atmosphere and its diurnal variability on sub-seasonal timescales. To complete this investigation, EMM will measure vertical temperature profiles from the surface to an altitude of 50 km. Along with Investigation 2, EMM will sample the Martian lower atmosphere on spatial and temporal scales sufficient to elucidate the processes driving global circulation in the current Martian climate. To satisfy this investigation, the physical parameter to be derived is the atmospheric temperature profiles, measured through the absolute thermal infrared radiance of the ~15 µm CO_2 absorption feature, and the surface temperature of Mars, measured through the absolute radiance where the atmosphere is relatively transparent.

Investigation 2 is to 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 column integrated ice optical depth (measured at 12 µm and 320nm), column integrated dust optical depth (measured at 9 µm, 220 nm, 635 nm), column integrated ozone column abundance (measured at 260 nm), and the column integrated water vapor abundance (measured over the 25-40 µm spectral region).

Investigation 3 is to determine the abundance and spatial variability of key neutral species in the thermosphere on sub-seasonal timescales. During this investigation, EMM will measure the dynamics and energetics of the thermosphere, through which all escaping particles must travel, as it forms the lower boundary of the exosphere. To satisfy this investigation, the physical parameters needed are the column densities of oxygen (130.4 nm & 135.6 nm) and carbon monoxide (CO 4PG: 140–170 nm) 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 on a timescale of ~1 day and their impact on the exosphere is expected in a timescale of ~1 week.

Investigation 4 is to determine the three-dimensional structure and variability of key species in the exosphere and their variability on sub-seasonal timescales. This investigation is focused on the exosphere, the channel through which Mars' atmosphere escapes to space. 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. Hydrogen escape rates can be derived via EMM's 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 hydrogen velocity distribution can be better separated from the colder, bound component. Observations of the O I 130.4 nm FUV emission from 200 km altitude out to several Mars radii will allow the bound and escaping components of the atomic oxygen population to be separated and hence enable the determination of the rate of photochemical escape of atomic oxygen. 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.

EMM and Data Assimilation: Thanks to its innovative orbit and observation strategy, EMM will offer unprecedented coverage and sampling of the diurnal and seasonal cycle up to high latitudes. This should be very suitable for meteorological data assimilation

Within the EMM team, it is planned to apply the LMD-LETKF scheme (See Young et al. this issue) at least to the thermal observations (temperature, dust, water ice) to provide a 4D climatology (reanalysis) of the Martian atmosphere. Water vapor and ozone could also be assimilated with a realistic model and it could in theory be possible to perform data assimilation of thermospheric data. EMM acquired datasets will be made available to the scientific community and usable by different teams and with different schemes.

Summary: 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.

References:

[1] O. Sharaf, S. Amiri, S. AlMheiri, A. AlRais, M. Wali, Z. AlShamsi, I. AlQasim, K. AlHarmoodi, N. AlTeneiji, H. Almatroushi, M. AlShamsi, M. AlAwadhi, M. McGrath, P. Withnell, N. Ferrington, H. Reed, B. Landin, S. Ryan, B. Pramann (2017) Emirates Mars Mission (EMM) 2020 Overview.