Scientific Payload of The Emirates Mars Mission: Emirates eXploration Imager (EXI)

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Introduction: 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 the Martian atmosphere. However, many of these observations have been obtained from spacecraft in sun-synchronous orbits (i.e., providing a limited range of local times), leaving much of the Martian diurnal cycle unexplored. Because of the limited coverage, it has been difficult to delineate potential diurnal aspects of such basic things as dust and water ice optical depths, as well as to validate the various algorithms used in the "physics packages" of Martian dynamical models.

The Emirates Mars Mission (EMM), a mission set to be launched in 2020 by the United Arab Emirates, will be able to provide a dataset that can fill this observational gap by sampling contemporaneously both diurnal and seasonal timescales on a global scale. Using three complementary scientific instruments, EMM will further improve our understanding of the global circulation in the lower atmosphere and the connections to the upward transport of energy of the escaping atmospheric particles from the upper atmosphere. Aligned with MEPAG Goal II: "Understand the processes and history of climate on Mars", EMM will be satisfying four scientific investigations as illustrated in table 1 showing the connections between EMM and MEPAG objectives. Investigations 1 and 2 will be focusing on the lower atmosphere to determine the three dimensional structure and variability of atmospheric temperature and to determine the geographic and diurnal distribution of key constituents in the lower atmosphere respectively. While investigations 3 and 4 focus on determining the structure and variability in the Martian thermosphere and exosphere respectively. Table 1 summarizes the flow down from the motivating science questions, to the EMM mission objectives and investigations.

In our presentation, we will focus on EMM investigation 2 and one of the scientific payloads that satisfies it, the Emirates eXploration Imager (EXI).

Table 1 EMM Science Flow down

Motivating Questions	I. How does the Martian lower atmosphere respond globally, diurnally and seasonally to solar forcing?	II. How do conditions throughout the Martian atmosphere affect rates of atmospheric escape?	III. How do key constituents in the Martian exosphere behave temporally and spatially?
EMM Objective	A. Characterize the state of the Martian lower atmosphere on global scales and its geographic, diurnal and seasonal variability. (EMM Invest. 1&2)	B. Correlate rates of thermal and photochemical atmospheric escape with conditions in the collisional Martian atmosphere. (EMM Investigation 1-4)	C. Characterize the spatial structure and variability of key constituents in the Martian exosphere. (EMM Investigation 4)

EMM Investigation	1. Determine the three-dimensional thermal state of the lower atmosphere and its diurnal variability on sub-seasonal timescales.	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.	4. Determine the three-dimensional structure and variability of key species in the exosphere and their variability on sub-seasonal timescales.
Instruments	EMIRS	EMIRS, EXI	EMUS	EMUS

EXI Science Targets: Investigation 2 is to "determine the geographic and diurnal distribution of key constituents in the lower atmosphere on sub-seasonal timescales". This investigation will provides insight into the processes driving the global circulation in the current Martian climate by sampling key constituents (dust, water ice clouds and ozone) in the lower atmosphere on sufficient spatial and temporal scales. EXI will be able to capture the ice optical depth, dust optical depth as well as the column abundance of ozone.

Dust. Dust is one of the most abundant constituent and a major driver of the Martian atmospheric energy balance. Observing dust will allow us to have a better understanding of the behavior and evolution of the atmosphere. To better characterize the geographic, diurnal and seasonal distribution of dust, EXI will capture an image in the 205 – 235 nm and 620 – 680 nm spectral bands, from which optical depth of the dust can be retrieved. The ultraviolet band will provide the primary aspect of the optical depth retrieval, using the contrast of the dark dust against the bright background of Rayleigh scattering. Adding the 635 nm band range provides context, as well the ability to constrain the dust column during higher opacity events, i.e., a dust storm. It is our goal to combine these products with the EMM Emirates Mars InfraRed Spectrometer (EMIRS) measurements of dust optical depth at 9µm to directly constraint additional dust properties such as the mean particle size.

Water Ice clouds. Water ice clouds also play an important role in the Martian climate. In terms of their geographic, diurnal and seasonal distribution, water ice clouds are known to have an impact on the total energy balance, the transport of water and the photochemistry of the Martian atmosphere. In order to determine the column optical depth of the ice cloud, EXI will be observing Mars in the wavelength band from 300 – 340 nm. Exploiting the contrast of the bright clouds with the dark surface, we will derive the water ice optical depth in a manner similar to that of the Mars Reconnaissance Orbiter (MRO) MARs Color Imager (MARCI). As with dust, we will combine these optical depths with those for water ice from the EMIRS at the 12 um-based retrieval to constrain microphysical properties such the mean particle size.

Ozone. Ozone, and its spatial and temporal distribution, is important for understanding the photochemical processes of the Martian atmosphere. EXI will determine ozone geographic and diurnal distribution on sub seasonal timescales by imaging in the 245 – 275 nm band. The conversion of the observed radiance to an ozone column abundance will be based on the approach used by MARCI (i.e,.Clancy et al., 2016).

To better characterize the mesoscale behavior of these three constituents over both diurnal and seasonal timescales, a spatial resolution of 8 km or less will be required. As for obtaining the radiance of ice, dust and ozone absorption bands, we are targeting an accuracy of ± 5% . Table 2 summarizes the requirements for the physical parameters.

Table 2 EXI physical parameters and their observable requirements

Physical parameter	Observable Quantity	Observable Quantity Requirement
Ice column-integrated optical depth	radiance at 300-340nm	Radiometric accuracy ≤ 5% (± 0.03 optical depth)
Dust column-integrated optical depth	radiance at 205-235nm	Radiometric accuracy ≤ 5% (± 0.1 optical depth)
Ozone column-integrated abundance	radiance at 245-275nm	Radiometric accuracy ≤ 5% (± 0.5μm-atm)

Implementation Overview: EXI is a multi-band, radiation tolerant camera capable of taking 12 megapixel images while maintaining the radiometric calibration needed for detailed scientific analysis. The instrument is being developed jointly by the Laboratory for Atmospheric and Space Physics (LASP) and Mohammed Bin Rashid Space Centre (MBRSC). It has a dual lens assembly separating the UV and VIS optical paths. EXI uses a selector wheel mechanism with of 6 discrete bandpass filters, 3 UV bands and the RGB bands.

Concept of Operation: EXI will be capable of providing simultaneous observations to fulfill navigation, public relations (PR) and science products. Based on the current orbit parameters, EXI will be capable of observing nearly complete local time coverage of Mars throughout one full Martian year. The resulting dataset will cover key seasonal information for more than 80% of the geographic area of Mars. These will be accomplished using three EXI observation sets. Two of which are science observations and the third serves PR needs. The science observation sets (EXI OS 1 and 2) consists of the four bands needed to observe the dust and ice optical depth as well as the ozone column abundance in the 220 nm, Red (635 nm), 320 nm and 260 nm. The difference is that OS2 has lower resolution (<64km resolution) and acts as a "bookmark" after EMIRS observation. While EMIRS is taking its observation, the planetary locations and local times within the field of view change and shift for EMIRS compared to EXI. Therefore, this second strategy is to ensure that any missing observation is being covered from the first EXI observation, which will then be overlapped with EMIRS observation data. While in third observation set (EXI OS 3), it consists of three bands in the Red (635 nm), Green (564 nm) and Blue (437 nm) in order to produce beautiful image of Mars for PR purposes.

Data Completeness and Utilization: To understand the linkages between the aerosols and ozone and their impact, it is important to measure the diurnal variability of the Martian atmosphere happening across the seasons. EXI will be able to sample most local times on weekly timescales providing us with unique measurements in different areas of the Martian globe. In order to capture the variability of the aerosols and ozone across seasons, a 10-day sampling period is required. As for the geographic coverage, EXI will be able to sample nearly all longitudes and latitudes less than 72 hours providing rapid and continuous monitoring of any cloud and dust events during a Martian year.

Instrument Calibration: The instrument is currently undergoing Post Environmental calibration activities. These will include the following:

1) Field of View Mapping (FOV) — edge determination (vignetting)
2) Focus / distortion mapping — uses collimated light source of comparable brightness to Mars.
3) Flat field / Radiance Transfer — measures the FOV response using calibrated diode monitoring of the beam provide by a Laser Driven Light Source (LDLS);
4) Channel Bandpass shape / Absolute Radiance — measures the spectral shape of each channel, including out-of-band rejection (i.e., red leak). A LDLS is used and NIST traceable photodiodes to provide absolute radiometry.

The results of the above tests will be combined with others such as detector characterization to provide an absolute radiometric calibration with an error budget. This will be reported as part of the presentation.

Several post-launch tests are planned with EXI, with the goal of looking for any changes associated with launch and during cruise. In addition, on-orbit monitoring will be performed to characterize any degradation of photometric performance. These tests include:

1) Post-launch alignment pointing and FOV mapping, using star field observation;
2) Flat Field trending – "delta" flat, using an on-board LED;
3) Blur Flat Field, using Mars as a target during the transition orbit;
4) Degradation Tracking, through photometric monitoring of specific Martian regions.