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Scientific payload of the Emirates Mars Mission: Emirates Exploration Imager (EXI)

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Abstract

The Emirates eXploration Imager (EXI) instrument is one of three scientific instruments abroad the Emirate Mars Mission (EMM) spacecraft, “Hope”. The planned launch window opens in the summer of 2020, with the goal of this United Arab Emirates (UAE) mission to explore the dynamics of the Martian atmosphere through global spatial sampling which includes both diurnal and seasonal timescales. A particular focus of the mission is the improvement of 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. This will be accomplished using three unique and complementary scientific instruments. The subject of this presentation, EXI, is a multi-band, camera capable of taking 12 megapixel images, which translates to a spatial resolution of better than 8 km with a well calibrated radiometric performance. EXI uses a selector wheel mechanism consisting of 6 discrete bandpass filters to sample the optical spectral region: 3 UV bands and 3 visible (RGB) bands. Atmospheric characterization will involve the retrieval of the ice optical depth using the 300-340 nm band, the dust optical depth in the 205-235nm range, and the column abundance of ozone with a band covering 245-275 nm. Radiometric fidelity is optimized while simplifying the optical design by separating the UV and VIS optical paths. The instrument is being developed jointly by the Laboratory for Atmospheric and Space Physics (LASP), University of California, Boulder, USA, and Mohammed Bin Rashid Space Centre (MBRSC), Dubai, UAE.

1. 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 Mars atmosphere. However, a large part 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. 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 unique and complementary scientific instruments [1][2], 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 cli-mate on Mars” [3], EMM will be satisfying four scientific investigations as illustrated in the traceability table below for EMM objectives and investigations. 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 investigation 3 and 4 focuses 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 this poster, we will focus on EMM investigation 2 and one of the scientific payloads that satisfies it, the Emirates eXploration Imager (EXI).

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

2. EXI Science Targets

Table 1: EMM Science Flow

Investigation 2 is to "determine the geographic and diurnal distribution of key constituents in the lower atmosphere on sub-seasonal timescales". This investigation will help in better understanding the processes that are 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 and the column abundance of ozone.

2.1 Dust

Dust is one of the most abundant constituent and a major driver of the Martian atmospheric energy balance. Ob-serving 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 – 235nm and 620 – 680nm spectral bands, where the optical depth at 220nm 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 635nm 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.

2.2 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 acquire the column optical depth of the ice cloud, EXI will be observing Mars in the wavelength band from 300 – 340nm. 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 12um-based retrieval to constrain microphysical properties such the mean particle size.

2.3 Ozone

Ozone, and its spatial and temporal distribution, is important in understanding the photochemical processes of the 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).

Table 2: EXI physical parameters

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)

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

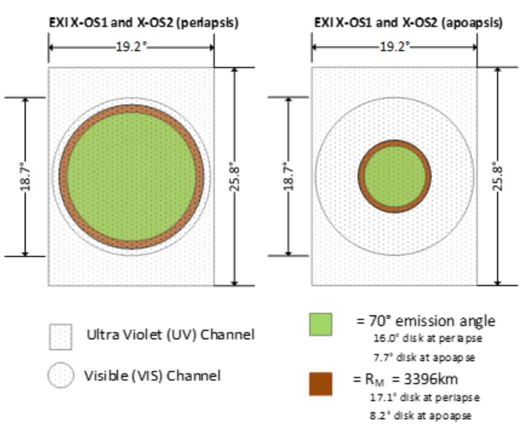
3. Implementation Overview

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 consisting of 6 discrete bandpass filters, 3 UV bands and the RGB bands. Table 3 and figure 1 summarizes EXI instrument specifications.

Table 3: EXI Instrument Specifications

Specification	UV	VIS
Focal Plane Format	12.6 MP 4:3 format 4096×3072 @ 5.5 µm	
Technology	CMOS	
Dynamic Range	12-bit, 13,500 e⁻ full well	
Lens System	48 mm, f/3.6	51 mm, f/4.25
Field of View	19.0°	25.8° by 19.2°
Pixel Angular View	23 arcsec per pixel	22 arcsec per pixel
Plate Scale	0.85 mm/°	0.90 mm/ °
Distortion @ 9.35°	+6%	-2%
Ground coverage at apoapsis	Full disk	
Ground resolution at apoapsis	4.9 km per pixel	4.6 km per pixel
Ground coverage at periapsis	Full disk	
Ground resolution at periapsis	2.3 km per pixel	2.2 km per pixel

Figure 1 EXI Coverage at Periapsis and Apoapsis



4. 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 cov-er 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 220nm, Red (635nm), 320nm and 260nm. The difference is that OS2 has lower resolution (<64km resolution) as it is done following 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 (635nm), Green (564nm) and Blue (437nm) in order to produce beautiful image of Mars for PR purposes. Table 4 summarizes EXI observation strategies.

Table 4: EXI Observational Strategy

Observation Strategy	Observation Strategy Set
EXI OS 1 (science)	4 Contemporaneous images • 220 nm, 260 nm, 320 nm, 635 nm • Incident <80°; emergence < 70° • 2 x 2 pixel binning (≤ 0.19 mrad spatial resolution) 2 dark images (for each detector)
EXI OS 2 (science)	4 Contemporaneous images • 220 nm, 260 nm, 320 nm, 635 nm • Incident <80°; emergence < 70° • 16 x 16 pixel binning (≤ 0.49 mrad spatial resolution) 2 dark images (for each detector)
EXI OS 3 (PR)	3 Contemporaneous visible images • 437 nm, 546 nm, 635 nm • Full resolution (≤ 0.11 mrad spatial resolution)

5. 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. Table 5 summarizes the EXI coverage and sampling requirements.

Table 5: EXI Coverage Requirement

EXI Coverage Requirement	
Diurnal Requirement	In any given span of 10 days, the 4 three-hour intervals spanning 6am-6pm local time are sampled with at least 80% coverage of longitude in: ≥ 3 local time intervals for all latitude equatorward of ±30° ≥ 2 local time intervals for all latitude equatorward of ±50° In any given span of 10 days, at least one in the 4 three-hour intervals spanning 6am-6pm local time is sampled with at least 50% coverage of longitudes for all latitudes equatorward of ±80°
Geographic Requirement	≥ 80% of the geographic area of Mars sampled more frequently than every 72 hours. Latitudes ≤80° sampled more frequently than every 72 hours.
Seasonal Requirement	Observations over 1 full Martian year (Goal: 20 of the 24 15° intervals of L_s sampled)

References:

[1] Khalid Badri, Eman Altunaiji, Christopher Edwards, Michael Smith, and the EMIRS Team (2018). Scientific Payload of the Emirates Mars Mission: Emirates Infrared Spectrometer (EMIRS) Overview.

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[3] Mars Exploration Program Advisory Group, "2015 MEPAG Goals Document," NASA, 24 02 2015. [Online]. Available: http://mepag.nasa.gov/meeting/2015-02/10_Goals%202015%20MEPAG_v6.pdf.