Science Closure Strategy for the Emirates Mars Mission

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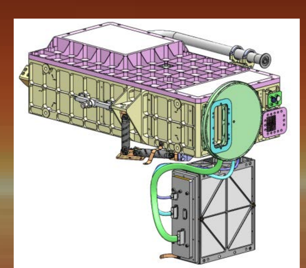
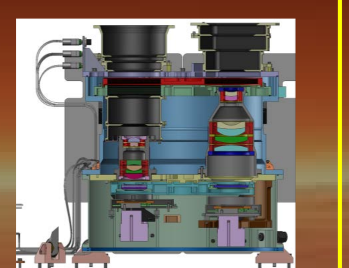
Overview

The 2020 Emirates Mars Mission (EMM) is focused on understanding the patterns of mass and energy transport within the Martian atmosphere and the processes that drive them, both laterally and vertically, and how they influence rates of atmospheric escape. EMM has three separate science objectives, addressed using synoptic observations in the visible, infrared and ultraviolet. The EMM science team has identified several science analyses necessary to achieve our objectives. Objective A is to characterize the state of the Martian lower atmosphere on a global spatial scale and across diurnal, sub-seasonal, and seasonal temporal scales. Objective B is to correlate rates of thermal and photochemical escape with conditions in the collisional Martian atmosphere. Objective C is to characterize the spatial structure and variability of hydrogen and oxygen in the Martian exosphere. The scientific analyses to address these objectives require a tailored combination of EMM and non-EMM data products, data analysis tools and physics-based models. Only with these unique combinations of data and models will we understand the physical processes driving atmospheric structure, dynamics, the connections between the lower and upper atmospheres, and how these connections influence atmospheric escape.

Emirates Mars Mission Instruments

EMIRS (ASU/MBRSC)

Fourier Transform IR Spectrometer
- ~300 spectral bands from 6-40+ µm
- Resolution <300 km

Measurements:
- T(z)
- τ_{ice} @ 12 µm
- τ_{dust} @ 9 µm
- H_2O column abundance

EMUS (LASP/SSL/MBRSC)

Ultraviolet Imaging Spectrometer
- Spectral Range: 100-170nm
- Spectral Resolution: 1.3, 1.8, 5 nm

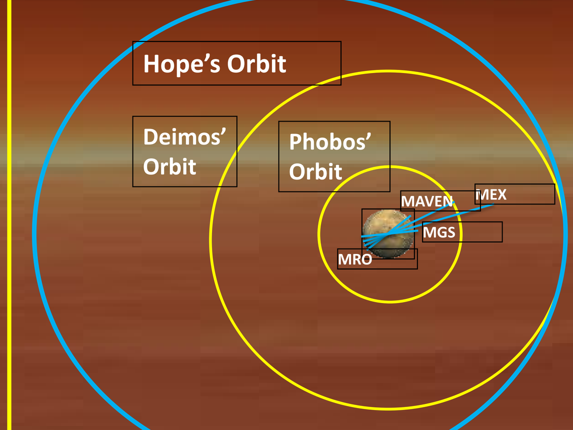
Measurements:
- Coronal H density
- Coronal O density
- Thermosphere O/CO ratio

EXI (LASP/MBRSC)

12 MPixel imager with 6 bandpass filters (VIS/UV)
- Resolution <10 km

Measurements:
- τ_{ice} @ 320 nm
- τ_{dust} @ 220 nm
- O_3 column abundance (260 nm)

Mission Plan



Key Features:
- Periapse altitude: 20,000 km
- Apoapse altitude: 43,000 km
- Orbital period: 55 hours
- 3 orbits per week, 2.24 sols per orbit
- Inclination: 25 deg
- Periapse placed near equator:
- Primary science collection begins ~May 2021

	Objectives / Science Closure Analyses	1.1Temperature profiles	1.2 Surface Temperature	2.1.1 ice optical depth at 320 nm	2.1.2 ice optical depth at 12 µm	2.2.1 dust optical depth at 220 nm	2.2.2 dust optical depth at 9 µm	2.3 Ozone column abundance	2.4 H_2O column abundance	Visible Images of Mars	3.1 Thermospheric O, CO column	4.1 Density of Hydrogen Corona	4.2 Density of Oxygen Corona	EUV irradiance at Mars (estimate)	MAVEN Particle and fields data	MRO Mars Climate Sounder Data	TGO Solar Occultation Data	JMARS Visualization tool	GCM simulation database	Data Assimilation Model	1D Atmospheric photochemistry model	Thermospheric H, O production models	ENLIL Space Weather Model	3D Oxygen Photochemical escape model	3D Hydrogen Jeans Escape Model
		EMM Instrument Data Products: EMIRS, EXI, EMUS												Non-EMM Data	Supporting Data Not Required			Tools	Physics-based models						
A	Characterize the state of the Martian lower atmosphere on global scales and its geographic, diurnal and seasonal variability.																								
i	Create combined multi-dimensional snapshot of the global atmosphere every 10 days	✓	✓	✓	✓	✓	✓	✓	✓									✓							
ii	Compare products of similar quantities between EXI and EMIRS			✓	✓	✓	✓											✓							
iii	Spatial and temporal comparisons to GCM results and other spacecraft data sets	✓	✓	✓	✓	✓	✓	✓	✓							✓	✓	✓	✓						
iv	Meteorological Data Assimilation	✓	✓	✓	✓	✓	✓	✓	✓										✓	✓					
B	Correlate rates of thermal and photochemical atmospheric escape with conditions in the collisional Martian atmosphere.																								
i	Correlate conditions in the lower and upper atmosphere simultaneously.	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓					✓	✓		✓				
ii	Compare escape rate variations with thermospheric conditions										✓	✓	✓									✓		✓	✓
iii	Study episodic events and their responses																								
1	Dust storm effects on escape rates	✓				✓	✓					✓	✓					✓	✓					✓	✓
2	Solar flare effects on escape rates											✓	✓	✓					✓					✓	✓
3	SEP/CME event effect on escape rate														✓				✓			✓	✓	✓	✓
4	Polar cap variability	✓								✓								✓	✓						
5	Dust deposition and removal events	✓								✓								✓	✓						
C	Characterize the spatial structure and variability of key constituents in the Martian exosphere.																								
i	Comparison of EMUS derived densities with model predictions											✓	✓	✓					✓			✓		✓	✓
ii	Derivation of hydrogen and oxygen escape rates and variability from density profiles											✓	✓	✓					✓			✓		✓	✓
iii	Comparison of derived escape rates to model predictions											✓	✓	✓					✓			✓		✓	✓

Table 1: Matrix of the EMM and non-EMM data products, plus tools and physics-based models that will be necessary to address each of our planned science closure analyses.

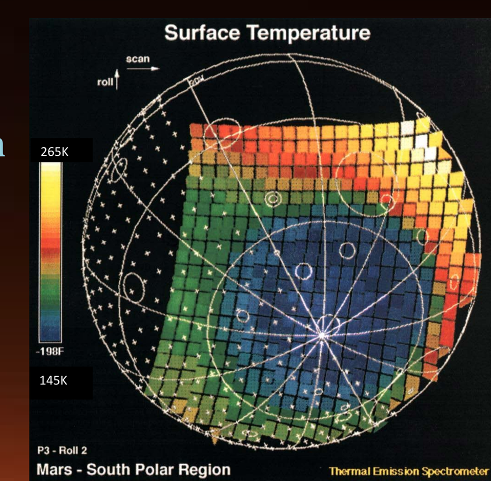
Objective A

Characterize the state of the Martian lower atmosphere on global scales and its geographic, diurnal and seasonal variability.

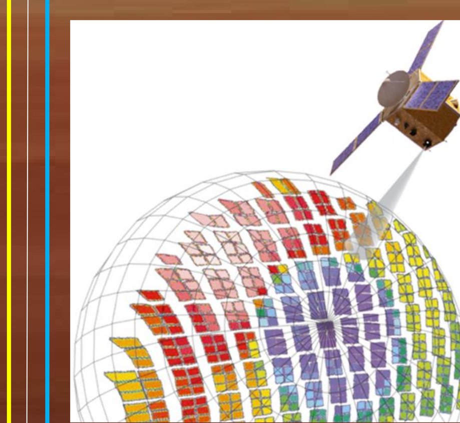
A.I Merge observations into a complete multi-dimensional snapshot of the global atmosphere (every ~10 days)

Trends will be easily identified and visualized with JMARS.

τ_{ice}, τ_{dust}, T, and H_2O, O_3 abundances with respect to:
- Latitude
- Longitude
- Altitude (for temperature only)
- Local time
- Season



A.II Compare products of similar quantities: EXI and EMIRS



EMIRS pixels: 125-300 km

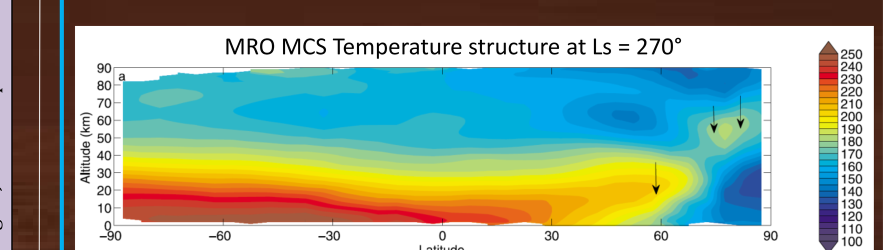
	EXI	EMIRS
τ_{dust}	220 nm	9 µm
τ_{ice}	320 nm	12 µm

EMIRS and EXI measure ice and dust optical depth at different wavelengths, sensitive to different grain sizes.

EXI provides global images like this image from MGS MOC.

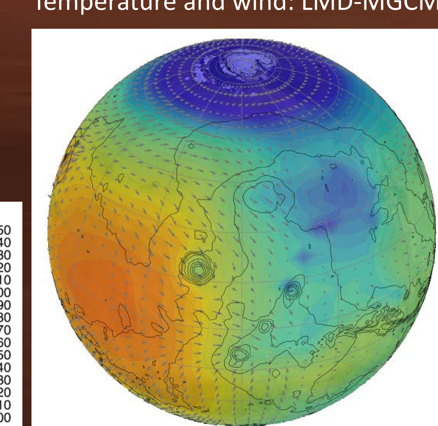
A.III Spatial and temporal comparisons to: i) GCM results and ii) other spacecraft data sets

Quantitative comparisons:
- with models reveal physical processes
- with other data sets (e.g. TGO NOMAD/ ACS, MRO MCS/MARCI) enables and reveals interannual variability



Heavens et al., 2011

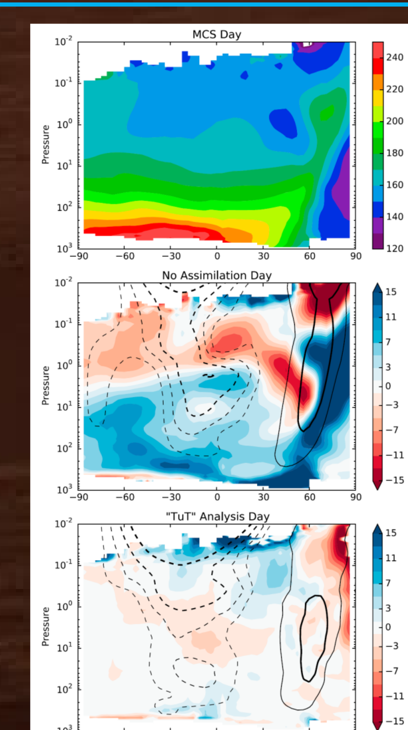
Temperature and wind: LMD-MGCM



Forget, Millour et al., 2011

A.IV Meteorological Data Assimilation

- The goal of data assimilation is to efficiently combine all available information, whether from observations or physical models.
- Data assimilation is different for Mars and more challenging, due to the atmosphere being less chaotic and exhibiting more global features than on Earth.
- EMM's uniquely global perspective on the Mars atmosphere should allow data assimilation to improve significantly over prior efforts using fixed-local time data sets.



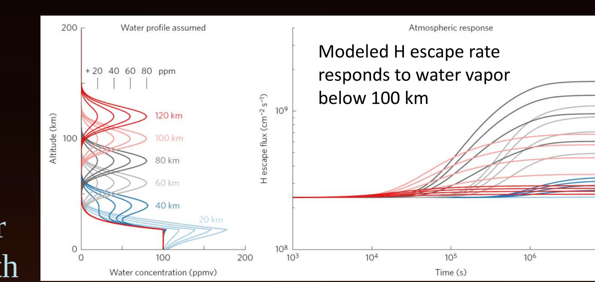
Navarro et al., 2017

Objective B

Correlate rates of thermal and photochemical atmospheric escape with conditions in the collisional Martian atmosphere.

B.I Correlate conditions in the lower and upper atmosphere simultaneously.

- Determine the likelihood that a lower atmospheric quantity (e.g. τ_{ice}, τ_{dust}, T, and H_2O, O_3) covaries with an upper atmospheric quantity (e.g. exobase H density or T, O/CO mixing ratios).
- Quantities need not vary simultaneously or in the same locations: expected to vary with some time lag and/or spatial shift or spread. Cross-correlation analysis will be applied.
- Strong correlations will suggest a physical link between quantities, and can be compared with future EMM observations, previous and future spacecraft measurements, and theoretical models to facilitate interpretation.

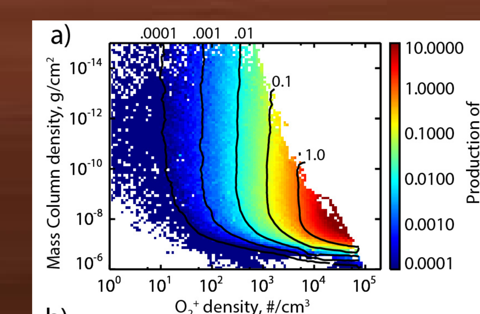


Chaffin et al., 2017

B.II Compare O & H escape rate variations with thermospheric conditions

- Particles escaping via photochemical and thermal processes acquire their energy in the upper thermosphere
- Conditions therein are therefore likely to be important for controlling escape rates.
- Thermosphere is influenced from the lower atmosphere below and above by the sun and solar wind above.
- Thus, EMM observations will be used to analyze how thermospheric conditions influence escape rates of hydrogen and oxygen.

Photochemical escape rates of O depend on the relative altitudes of thermospheric neutrals and O_2^+ ions

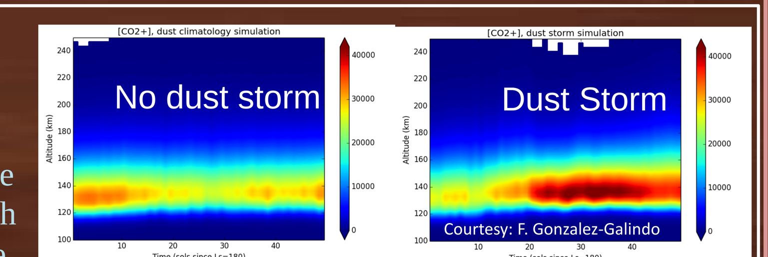


Lillis et al., 2017

B.III Study episodic events and their responses

1. Dust storm effects on escape rates

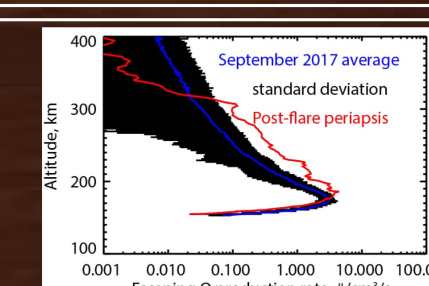
Dust storms deplete O in the thermosphere, altering the relative production of O_2^+ and CO_2^+, which cause escape through dissociative recombination.



O_2^+ and CO_2^+ dissociatively recombine to cause escape.

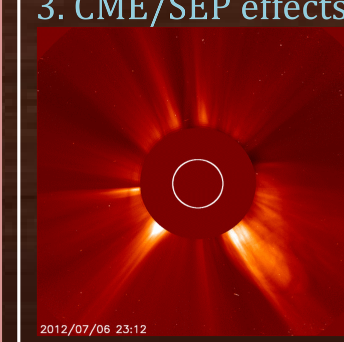
2. Solar Flare effects on escape rates

Solar flares cause increased:
- Ionization, causing photochemical escape of O.
- Thermospheric temperatures, causing thermal escape of hydrogen.

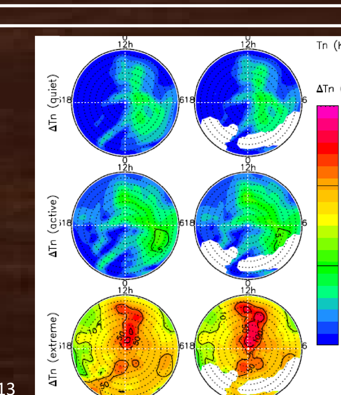


Thiemann et al., 2018

3. CME/SEP effects on escape rates

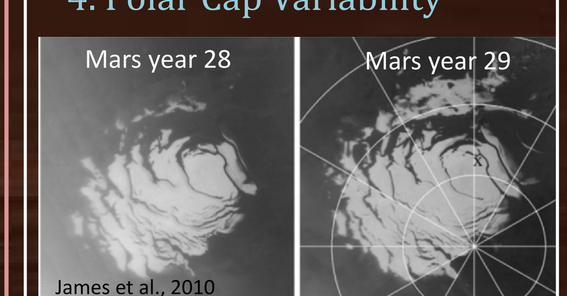


CME events can provide and drive significant precipitation of solar and planetary ions to the upper atmosphere, causing heating and chemistry changes.



Fang et al., 2013

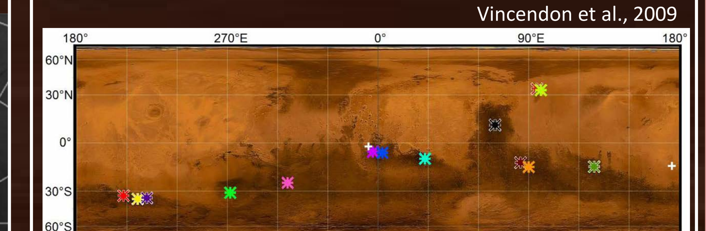
4. Polar Cap Variability



EXI will monitor polar cap variability

5. Dust Deposition and Removal Events

Vincendon et al., 2009



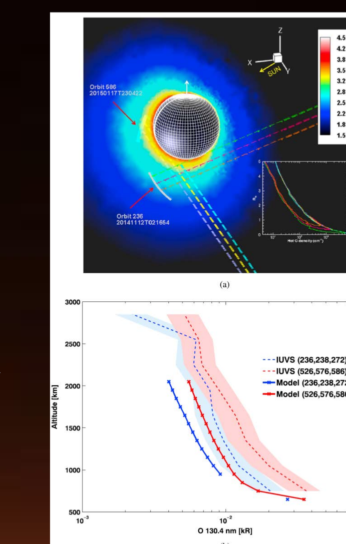
EMIRS surface TIR albedo measurements will reveal large-scale dust motions over time.

Objective C

Characterize the spatial structure and variability of key constituents in the Martian exosphere.

C.I Comparison of EMUS derived densities with model predictions

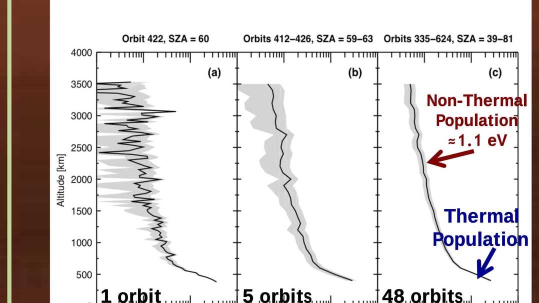
- Models predict radial, latitudinal, and SZA variability of O and H exospheres.
- Models may not include all relevant sources or accurately capture asymmetries.
- The following EMUS observations will be used to create 3-D representations of O, H densities and compared with models to reveal additional sources and processes.
  - OS-2 images of the inner O corona
  - OS-3 asterisk-shaped observations of H corona.
  - OS-4 radial profiles of O and H out to 11 R_{Mars}.



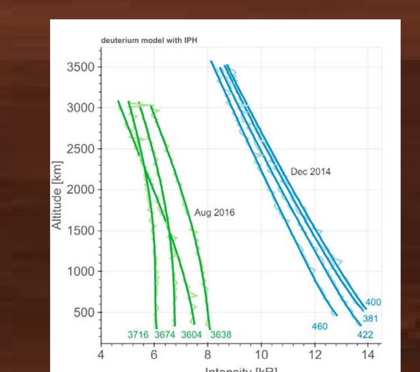
Lee et al., 2015

C.II Derivation of hydrogen and oxygen escape rates and variability from density profiles

- Knowledge of sources of hot O and H are necessary to fit models of O and H escape to EMUS-derived density profiles of same.



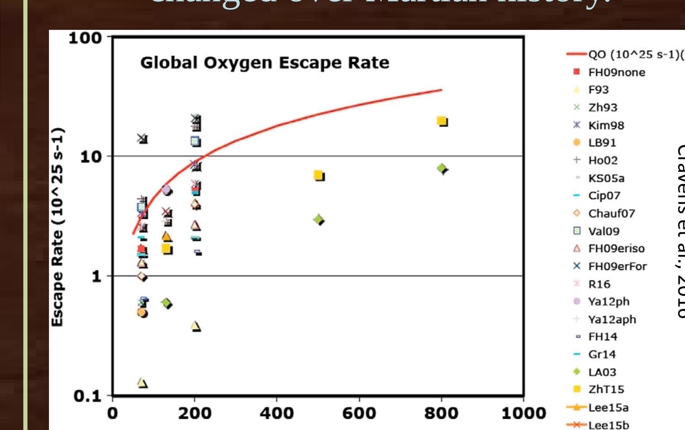
MAVEN IUVS O 130.4 nm profiles are consistent with models of O escape w/ rates of 6 x 10^{25} s^{-1}.



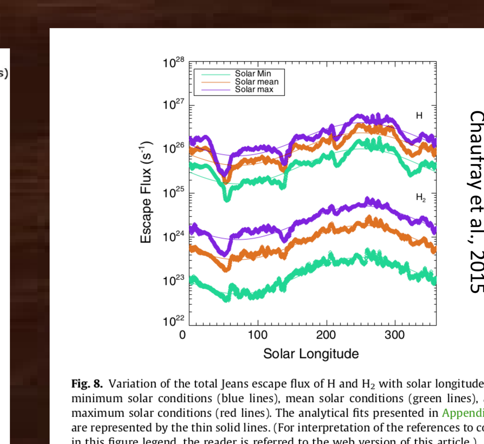
2-component H models matching MAVEN IUVS Lyman alpha (121.6 nm) profiles give escape rates of ~1 – 8 x 10^{26} s^{-1}.

C.III Comparison of derived escape rates to model predictions

- Quantitative comparisons between derived escape rates and model predictions reveal physical process in important for understanding and simulating how escape rates may have changed over Martian history.



Global models of photochemical O escape predict a wide range of escape rates with respect to solar EUV flux. Definitive O escape rates from EMUS will narrow down the range of appropriate models.



Models of H escape flux variation based on lower atmosphere simulations can reproduce the ~order of magnitude seasonal variability of escape rates.

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Questions?

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