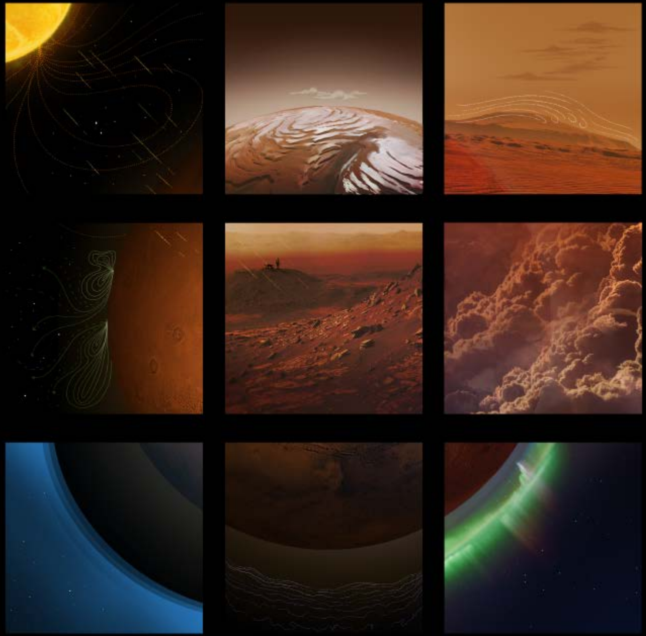
MOSAIC Concept Study

Final report delivered to NASA & NASEM August 7



MOSAIC

MARS ORBITERS FOR
SURFACE-ATMOSPHERE-IONOSPHERE
CONNECTIONS

AUGUST 2020
Mission Concept Study
Planetary Science Decadal Survey

National Aeronautics and Space Administration
www.nasa.gov

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Mars Orbiters for Surface-Atmosphere-Ionosphere **Connections**

Rob Lillis & the MOSAIC team

Presented to the Planetary Science Decadal Survey
2022-2032
Panel on Mars
Meeting No. 4
November 30, 2020

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~125 people contributed

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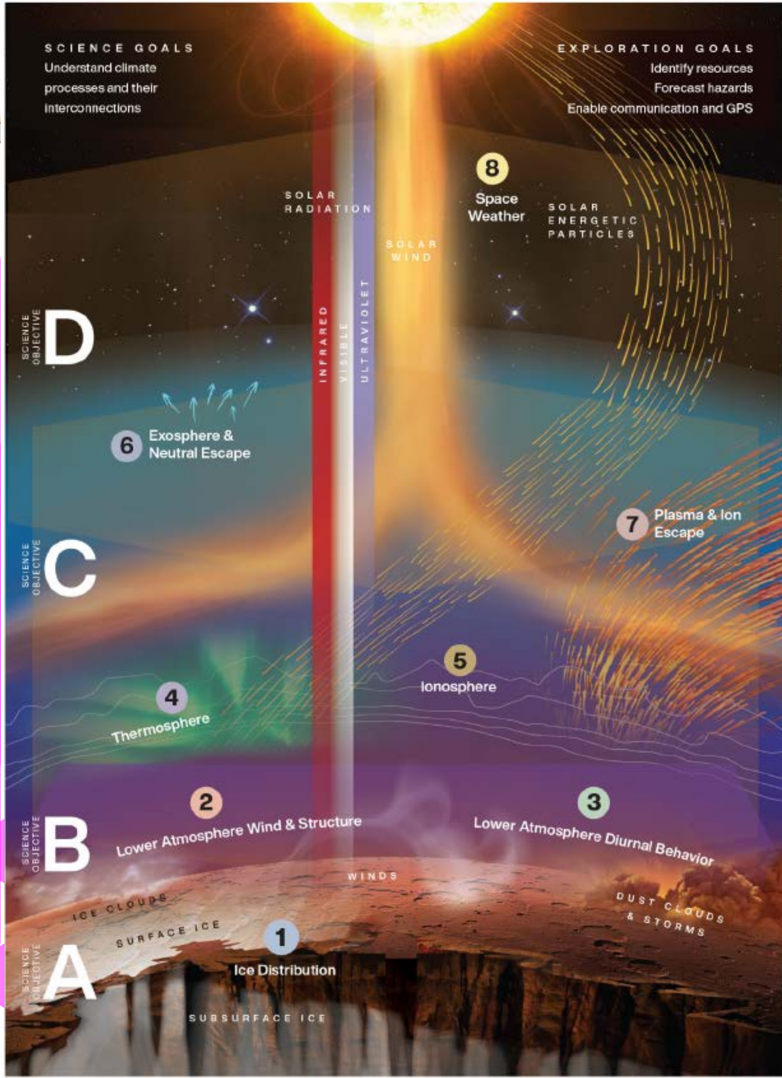
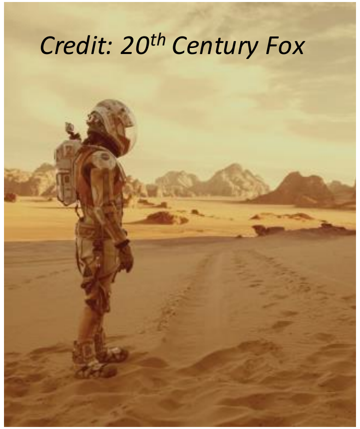
Science Traceability

MOSAIC GOALS	Mission Objectives	Investigations:	1. Ice distribution	2. Atmosphere structure	3. Atm. Diurnal behavior	4. Thermosphere	5. Ionosphere	6. Exosphere/neutral esc	7. Plasma /ion escape	8. Space weather
I. Understand Mars's present day climate processes and their inter-connections, from the sub-surface to the solar wind	I.D Characterize fields and plasma flows in the upstream solar wind and throughout the magnetosphere and upper ionosphere, separating spatial from temporal variability.						✓	✓	✓	✓
	I.C: Correlate variability in the thermosphere, ionosphere, and escape rates to:	The space weather environment				✓	✓	✓	✓	✓
		The lower-middle atmosphere.		✓	✓	✓	✓	✓	✓	
	I.B: Characterize the structure and dynamics of the Martian lower-middle atmosphere on meso- and global scales, and its geographic, diurnal, and seasonal variability.			✓	✓					
	I.A: Characterize volatile cycling between the subsurface, surface and atmospheric reservoirs.		✓	✓	✓					



Preparing for Human Exploration

MOSAIC GOALS	Exploration Objectives	Investigations	1. Ice distribution	2. Atmosphere structure	3. Atm. Diurnal behavior	4. Thermosphere	5. Ionosphere	6. Exosphere/neutral esc	7. Plasma /ion escape	8. Space weather	9. Tech Demonstration
II. Identify hazards, characterize resources, and demonstrate technologies to enable the Human Exploration of Mars.	Characterize potentially extractable water ice resources to support ISRU.		✓								
	Allow accurate data assimilation and weather forecasting.			✓	✓						
	Characterize neutral winds in the mesosphere/thermosphere for aerobraking.					✓					
	Study ionospheric variability to mitigate disruptive effect on communication and GPS.						✓		✓	✓	
	Demonstrate high-bandwidth communication between Mars surface, Mars orbit, and Earth.										✓
	Characterize the environment of penetrating ions (>10 MeV/nuc) at 1.4-1.6 AU.									✓	



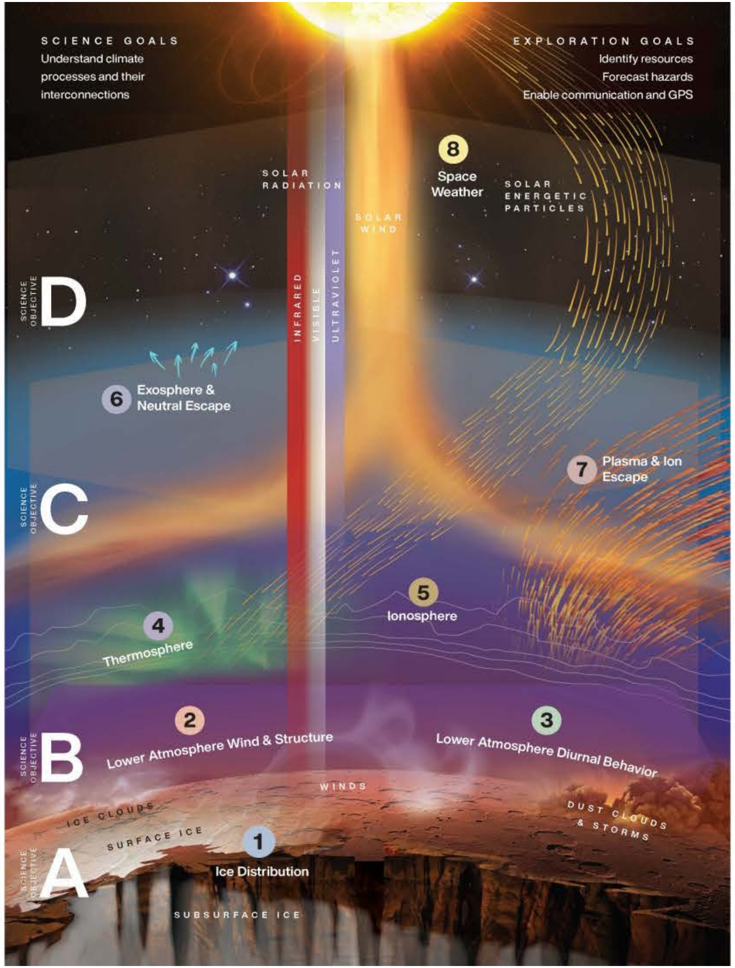
Relevant to NASA Exploration Goals. knowledge gap-filling activities identified by Precursor Strategy Analysis Group (PSAG):

1. ***Ice depth variation*** within the first meter (for drinking water & propellant synthesis). Activity D1-5, D1-6.
2. ***Weather forecasting***: dust climatology (B1-1), model validation (A2-1), global-scale T, wind, aerosols (A1-1, A1-2, A1-3).
3. ***Communications & GPS***: high-bandwidth comms (A4-2), delay-tolerant networking, Global positioning, and continuous Earth comm with all longitudes.

MOSAIC Traceability

Goals to Investigations

MOSAIC GOALS	KEY MOTIVATING QUESTIONS	MISSION OBJECTIVES	1. Ice Distribution	2. Atmosphere Structure	3. Atmosphere Diurnal Behavior	4. Thermosphere	5. Ionosphere	6. Exosphere & Neutral Escape	7. Plasma & Ion Escape	8. Space Weather	9. Technology Demonstrations
SCIENCE		**SCIENCE OBJECTIVES**									
I. Understand Mars's present day climate processes and their inter-connections, from the sub-surface to the solar wind.	How do volatiles move between the subsurface, surface, and atmosphere?	**A** Characterize volatile cycling between the subsurface, surface and atmospheric reservoirs.	●	●	●						
	How does the Martian lower-middle atmosphere respond diurnally, on meso- and global scales, to the seasonal cycle of insolation?	**B** Characterize the structure and dynamics of the Martian lower-middle atmosphere on meso- and global scales, and its geographic, diurnal, and seasonal variability.		●	●						
	How does coupling from the lower atmosphere combine with the influence of space weather (solar wind, SEPs, and solar EUV) to control the upper atmospheric system++ and drive atmospheric escape?	**C** Correlate variability in the thermosphere, ionosphere, and escape rates to: Conditions in the lower-middle atmosphere.		●	●	●	●	●	●		
		C Correlate variability in the thermosphere, ionosphere, and escape rates to: The space weather environment.				●	●	●	●	●	
		D Characterize fields and plasma flows in the upstream solar wind and throughout the magnetosphere and upper ionosphere, separating spatial from temporal variability.					●	●	●	●	
EXPLORATION		**EXPOLORATION OBJECTIVES**									
II. Identify hazards, characterize resources, and demonstrate technologies to enable the Human Exploration of Mars.	How, where, and when can future astronauts access extractable water ice resources?	Characterize potentially extractable water ice resources to support in situ resource utilization.	●								
	With what degree of accuracy can Martian weather be forecast, for operational purposes?	Characterize the Mars atmospheric state with sufficient spatial sampling and cadence to allow accurate data assimilation and weather forecasting.		●	●						
	How will mesospheric and thermospheric winds affect aerobraking spacecraft?	Characterize neutral winds in the mesosphere and lower thermosphere (60 km-130 km) and their variability with lower atmospheric conditions and solar activity.				●					
	How will space weather effects on the Mars ionosphere affect surface-surface and surface-orbit communications?	Characterize the Mars ionospheric state and variability sufficiently to determine its likely disruptive effect on communications and positioning.					●		●	●	
	How will energetic particle radiation affect astronauts in Mars orbit?	Characterize the environment of penetrating ions (>10 MeV/nuc) at 1.38-1.62 AU with season and solar cycle.								●	
	Can reliable high-bandwidth Earth-Mars communication be maintained?	Demonstrate delay-tolerant networking, Deep Space Optical Communication (DSOC), and relay communication between Mars surface, Mars orbit, and Earth.									●

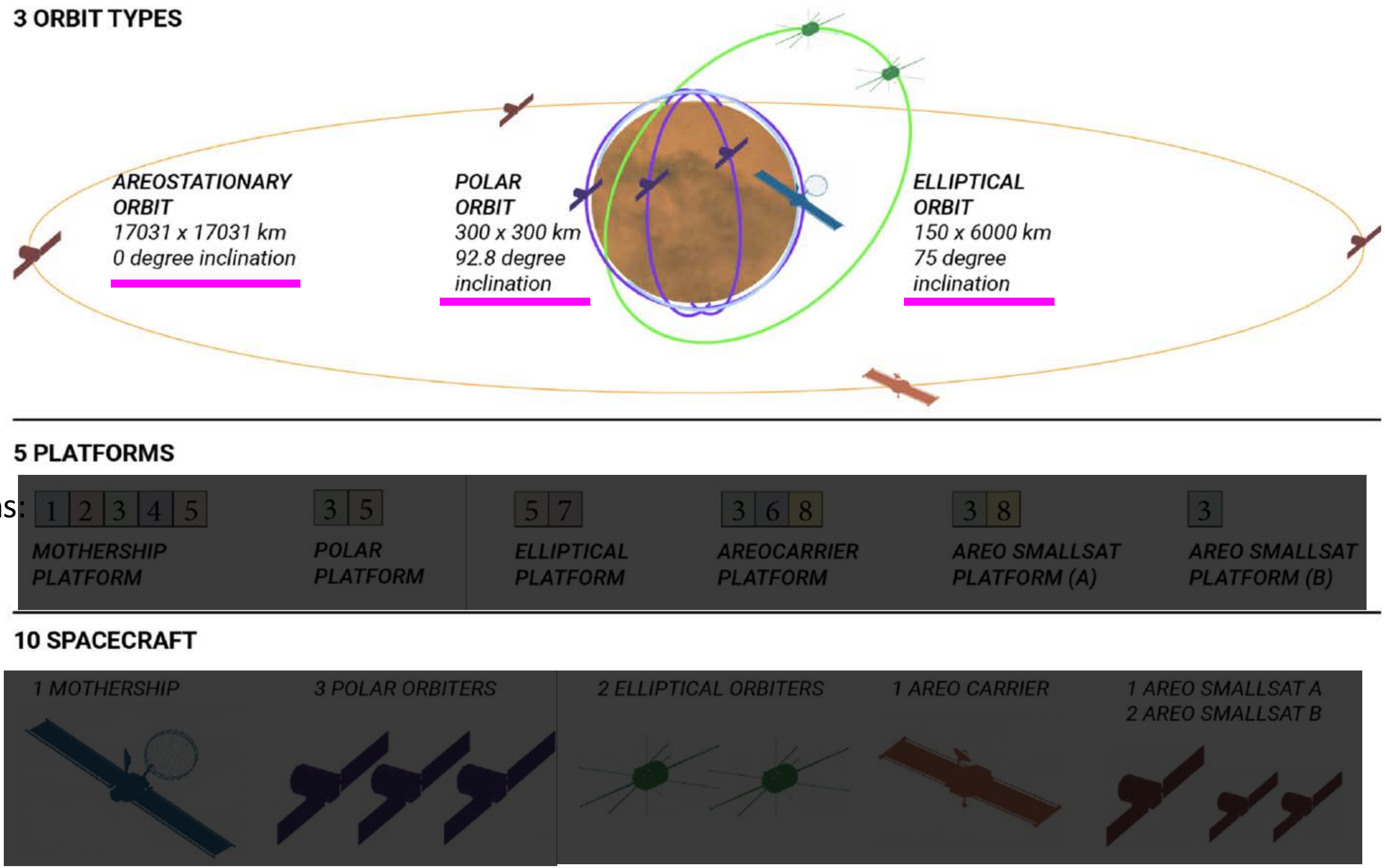


Investigations to Instruments

Table 1-2

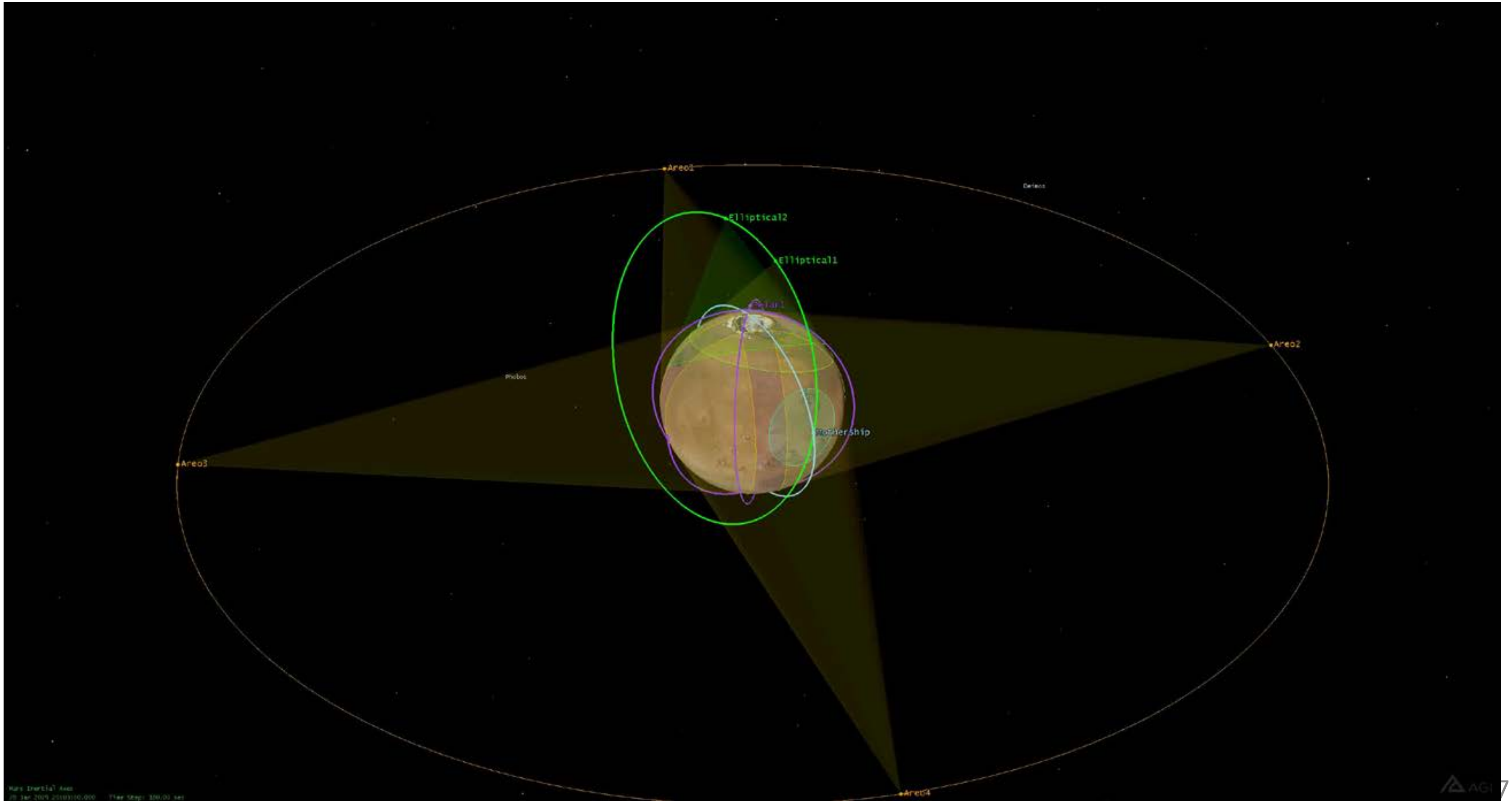
	INVESTIGATIONS	MEASUREMENTS	INSTRUMENTS+	FUNCTIONAL REQUIREMENTS
1	Measure the three-dimensional distribution of ice from the surface to 10 m below.	• Subsurface ice abundance derived from dielectric constant • Surface thermal inertia • Surface water ice & albedo	• P-band SAR & Sounder • Visible imager	<400 km circular near-polar orbit. Hi mass and power
2	Measure the geographic and altitude distribution of pressure, winds, aerosol concentrations, water vapor, ozone, and temperatures in the Mars lower and middle atmosphere.	• Vertical profiles (0-80 km) of: temperature, winds, dust, H_2O and CO_2 ices, H_2O vapor, O_3 • Surface temperature and pressure	• Thermal IR radiometer • Wind LIDAR • Sub-mm sounder	<400 km circular near-polar orbit
3	Measure the complete diurnal and geographic behavior of the atmosphere and evolution of Martian dust and ice clouds.	• Visible and/or UV imagery of clouds/hazes • Column opacities/abundances of dust, H_2O, ozone, and CO_2 ice • Temp/pressure profiles 0 - 40 km • Vertical profiles (0-80 km) of temperature, dust, H_2O and CO_2 ices, H_2O vapor, spread evenly across 8 local times	• Visible imager • Near IR spectrometer • Thermal IR radiometer • Radio occultation	Four Areostationary orbits, spaced evenly in longitude Four <400 km circular near-polar orbits, spaced evenly in local time
4	Measure the global 3-D composition, structure, and winds in Mars's thermosphere.	Vertical profiles (90 - 200 km) of: • Horizontal wind velocity • Density and temp. of O, CO, N_2, CO_2	• Wind Doppler interferometer • FUV/MUV spectrograph	<400 km circular near-polar orbit
5	Measure the global 3-D structure of Mars ionosphere.	Vertical profiles (90-400 km) of: • electron density • electron temperature	• Langmuir probe • Radio Occultation	< 400 km circular AND elliptical orbits < 170 km periapse
6	Measure the 3-D density and temperature structure of Mars's hydrogen and oxygen exospheres.	Vertical profiles (200 - 30,000 km) of: • O density and temperature • H density and temperature	• FUV/EUV spectrograph	Circular orbit >10,000 km altitude
7	Measure (from multiple viewpoints) fluxes of light and heavy ions, magnetic field and topology, plasma waves, and electric fields within and between all regions of Mars' hybrid magnetosphere.	• Magnetic field • Electric field • Suprathermal electron pitch angle distributions → magnetic topology • Ion mass, energy, and angular distributions. • Thermal electron temperature and density • Plasma waves	• Fluxgate magnetometer • Search coil magnetometer • Ion energy/angle/mass • Electron energy/angle • Electric fields	2 spacecraft Orbit inclination ~75°, Apoapsis >6000 km, <170 km periapse
8	Measure magnetic field and plasma conditions in the upstream solar wind, and solar extreme ultraviolet irradiance.	• Magnetic field • Solar wind density, speed, temp • Solar EUV irradiance • Solar Energetic Particle Flux	• Fluxgate Magnetometer • Ion energy/angle • Electron energy/angle • Extreme UV monitor • Energetic ion/electron	2 spacecraftCircular orbit >10,000 km altitude
9	Demonstrate delay-tolerant networking (DTN), high-performance onboard processing, high-bandwidth optical Earth-comm, and continuously available relay communication between Mars surface and Earth via relay.		• Electra/Relay antennas • Optical communication • DTN protocols	All

The MOSAIC Constellation



Investigations:

MOSAIC constellation movie



MOSAIC Descopes

Platform:	Polar-orbiting Mothership							Polar SmallSats		Elliptical SmallSats	Areostationary Satellites			Traditional cost	Newspace cost	Preserves	What is Lost?
Instrument:	P-band Radar	Wind LIDAR	Sub-mm Sounder	Doppler Interfer-ometer	FUV/MUV Spectro-graph	TIR radiometer Visible Camera NIR Spectr.	Relay	Mini TIR radiometer NIR spectrometer	Radio Occultation (includes mothership)	Magneto-sphere Plasma Package	EUV/FUV Spectro-graph	Space Weather Package	Mini TIR radiometer Viz. camera NIR spectr.	$FY25 with 50% reserves	$FY25 with 50% reserves		
$FY 20 ($M)	170	40	35	40	30	35	TBD	12 x 3 = 36	6 x 2 = 12	19 x 2 = 38	20	13x2 = 26	11 x 4 = 44				
Investigation	1	2	2	4	4	1,2		2, 3	3, 5	5, 7	6	8	3				
Baseline	1	1	1	1	1	1	1	3	6	2	1	2	4	4,220	4,060	Full MOSAIC Capability	
In case of Ice Mapper		1	1	1	1	1	1	3	6	2	1	2	4	Still in work	Still in work	Full top to bottom atmosphere sampling	Ice mapping & exchange of water with subsurface
Descope		1 of 2				1	1	3	6	2	1	2	4	3,073	2,910	Comprehensive lower atmosphere sampling	Above + Thermosphere Winds above 50 km
Descope Lite		1 of 2				1	1	2	4	1	1	1	3	Still in work	Still in work	Adequate lower atmosphere sampling	Above + Full diurnal coverage Ion escape short variability Full space weather coverage
Threshold						1						1	3	Discovery/ New Frontiers cost bin	Discovery cost bin	Bare minimum constellation providing multiple perspectives	Above + Boundary layer & Winds Ionosphere Magnetosphere Exosphere & neutral escape

Notes:

- Class B costs assumed.
- Class C, Class D will be lower cost.
- Threshold Class D Tailored single string will be ~50% of Discovery.
- JPL still working on robust cost estimates for various options.

MOSAIC: Sharing the Burden

MOSAIC

HEOMD may fund:

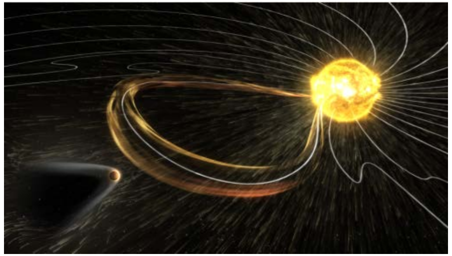
- Ice mapping
- Weather monitoring.
- X-band surface to areostationary relay comm.
- Radiation monitoring

STMD may fund:

- Delay-tolerant networking
- High-bandwidth Earth-Mars communications.

Heliophysics Division may fund:

- Space weather monitoring
- Magnetosphere measurements (ESCAPADE is funded by HPD)



Other space agencies:

- All copies of one instrument
- All copies of one platform
- Active coordination only required for occultations

European Space Agency
РОСКОСМОС
UAE SPACE AGENCY

Commercial partners:

- SpaceX May wish to partner with HEOMD.

Can other missions substitute pieces?

- Existing/planned spacecraft can fulfill aspects of MOSAIC Investigations, **but only if measurements are simultaneous**.

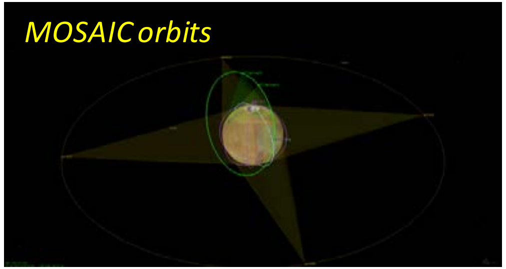
Mission Status	**Missions & Instruments**	**Investigations:**	1. Ice distribution	2. Atmosphere structure	3. Atm. Diurnal behavior	4. Thermosphere	5. Ionosphere	6. Exosphere, neutral escape	7. Plasma & ion escape	8. Space weather
Operational	Mars Reconnaissance Orbiter MCS			Partial						
	MAVEN Particles & Fields Package								Partial	
	MAVEN IUVS					Partial	Partial	Partial	Partial	
	Trace Gas Orbiter NOMAD & ACS			Partial	Marginal					
In Development	Emirates Mars Mission EXI, EMUS, & EMIRS (2021-				Partial	Partial		Baseline		
	China Tianwen-1 ion analyzer & magnetometer (2021-								Marginal	Marginal
	NASA ESCAPADE (2026- *not confirmed								Threshold	
	JAXA-ESA MMX MacrOmega, MSA, & IREM (2025-2028)				Partial				Marginal	Marginal
Concepts	Ice Mapper		Baseline							
	COMPASS		Baseline							

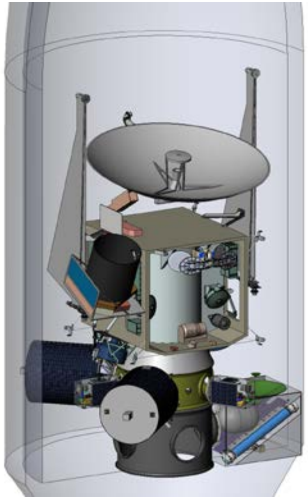
Fulfillment:

Dark green	Baseline
Light green	Threshold
Yellow	Partial
Orange	Marginal
White	None

Summary

- MOSAIC represents many of the next logical steps in orbital investigation of the Mars climate system.
  - Simultaneous systematic observations of relevant quantities are required for science closure.
  - Most investigations help prepare for human exploration.
- Full Constellation has a high price tag, but mitigations exist:
  - Other simultaneously-observing missions.
  - Cost-sharing with HEOMD, STMD, Helio Division.
  - Contributions from other agencies (instruments, platforms).
  - Threshold mini-constellation (4 SC) fits within Discovery or less, depending on mission class.

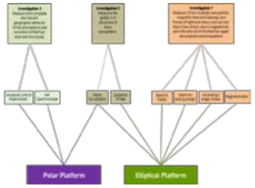


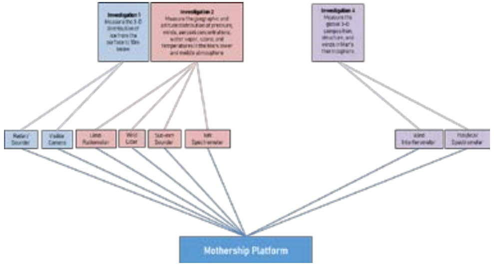


MOSAIC in Single 5 m fairing

MOSAIC cost can spread over 3 Mars launch opportunities

Spacecraft delivery via rideshare or propulsive tug element





2026

- 4 Areostationary SSc
- Delivered via rideshare – low DV prop capability
- Commercial SSc Builder (target <40M per ssc bus)
- DTE Using Iris and commercial antenna
- Optional: relay capability for future low Mars orbiters

2028

- 4-5 SSc
- Delivered via rideshare – very low DV prop capability
- Commercial SSc Builder (target <25M per SSc bus)
- Relay using exisiting relay network including Areo network

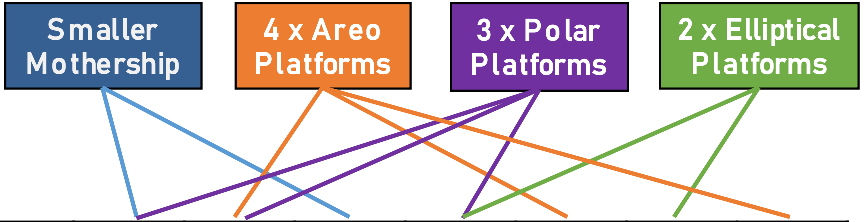
2031

Icemapper or another mission

Backup: MOSAIC Descope Science matrices

Case 1: No Ice Radar

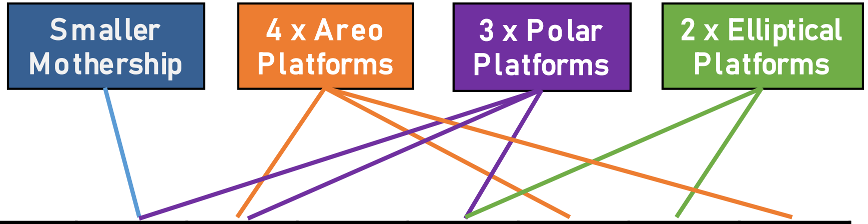
MOSAIC



Science & Exploration Goals	Scientific Objectives	Investigations:	1. Ice distribution	2. Atmosphere structure	3. Atm. Diurnal behavior	4. Thermosphere	5. Ionosphere	6. Exosphere, neutral escape	7. Plasma & ion escape	8. Space weather
I. Understand Mars's present day climate processes and their inter-connections, from the sub-surface to the solar wind	~~**I.A**: Characterize volatile cycling between the subsurface, surface and atmospheric reservoirs.~~			✓	✓					
	I.B: Characterize the structure and dynamics of the Martian lower-middle atmosphere on meso- and global scales, and its geographic, diurnal, and seasonal variability.			✓	✓					
	I.C: Correlate variability in the thermosphere, ionosphere, and escape rates to:	The lower-middle atmosphere.		✓	✓	✓	✓	✓	✓	
		The space weather environment				✓	✓	✓	✓	✓
	I.D: Characterize fields and plasma flows in the upstream solar wind and throughout the magnetosphere and upper ionosphere, separating spatial from temporal variability.						✓	✓	✓	✓
II. Identify hazards, characterize resources, and demonstrate technologies to enable the Human Exploration of Mars	~~**II.A:** Characterize potentially extractable water ice resources to support in situ resource utilization~~									
	II.B: Characterize the Mars atmospheric state with sufficient spatial sampling and cadence to allow accurate data assimilation and weather forecasting.			✓	✓					
	II.C: characterize neutral winds in the mesosphere and lower thermosphere (60 km-130 km) and their variability with lower atmospheric conditions and solar activity.					✓				
	II.D: Characterize the Mars ionospheric state and variability sufficiently to determine its likely disruptive effect on communications and positioning						✓		✓	✓
	II.E: characterize the environment of penetrating ions (>10 MeV/nuc) at 1.38-1.62 AU.									✓

Case 2: “Descope”

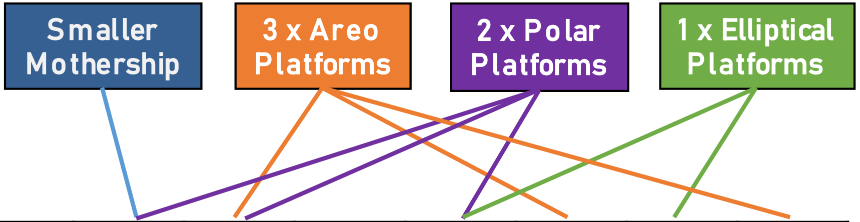
MOSAIC



Science & Exploration Goals	Scientific Objectives	Investigations:	1. Ice distribution	2. Atmosphere structure	3. Atm. Diurnal behavior	4. Thermosphere	5. Ionosphere	6. Exosphere, neutral escape	7. Plasma & ion escape	8. Space weather
I. Understand Mars’s present day climate processes and their inter-connections, from the sub-surface to the solar wind	~~**I.A**: Characterize volatile cycling between the subsurface, surface and atmospheric reservoirs.~~			✓	✓					
	I.B: Characterize the structure and dynamics of the Martian lower-middle atmosphere on meso- and global scales, and its geographic, diurnal, and seasonal variability.			✓	✓					
	I.C: Correlate variability in the ~~thermosphere~~, ionosphere, and escape rates to:	The lower-middle atmosphere.		✓	✓		✓	✓	✓	
		The space weather environment					✓	✓	✓	✓
	I.D: Characterize fields and plasma flows in the upstream solar wind and throughout the magnetosphere and upper ionosphere, separating spatial from temporal variability.						✓	✓	✓	✓
II. Identify hazards, characterize resources, and demonstrate technologies to enable the Human Exploration of Mars	~~**II.A:** Characterize potentially extractable water ice resources to support in situ resource utilization~~									
	II.B: Characterize the Mars atmospheric state with sufficient spatial sampling and cadence to allow accurate data assimilation and weather forecasting.			✓	✓					
	~~**II.C:** characterize neutral winds in the mesosphere and lower thermosphere (60 km-130 km) and their variability with lower atmospheric conditions and solar activity.~~									
	II.D: Characterize the Mars ionospheric state and variability sufficiently to determine its likely disruptive effect on communications and positioning						✓		✓	✓
	II.E: characterize the environment of penetrating ions (>10 MeV/nuc) at 1.38-1.62 AU.									✓

Case 3: “Descope Lite”

MOSAIC



Science & Exploration Goals	Scientific Objectives	Investigations:	1. Ice distribution	2. Atmosphere structure	3. Atm. Diurnal behavior	4. Thermosphere	5. Ionosphere	6. Exosphere, neutral escape	7. Plasma & ion escape	8. Space weather
I. Understand Mars’s present day climate processes and their inter-connections, from the sub-surface to the solar wind	~~**I.A**: Characterize volatile cycling between the subsurface, surface and atmospheric reservoirs.~~			✓	✓					
	I.B: Characterize the structure and dynamics of the Martian lower-middle atmosphere on meso- and global scales, and its geographic, diurnal, and seasonal variability.			✓	✓					
	I.C: Correlate variability in the ~~thermosphere~~, ionosphere, and escape rates to:	The lower-middle atmosphere.		✓	✓		✓	✓	✓	
		The space weather environment					✓	✓	✓	✓
	I.D: Characterize fields and plasma flows in the upstream solar wind and throughout the magnetosphere and upper ionosphere, separating spatial from temporal variability.						✓	✓	✓	✓
II. Identify hazards, characterize resources, and demonstrate technologies to enable the Human Exploration of Mars	~~**II.A:** Characterize potentially extractable water ice resources to support in situ resource utilization~~									
	II.B: Characterize the Mars atmospheric state with sufficient spatial sampling and cadence to allow accurate data assimilation and weather forecasting.			✓	✓					
	~~**II.C:** characterize neutral winds in the mesosphere and lower thermosphere (60 km-130 km) and their variability with lower atmospheric conditions and solar activity.~~									
	II.D: Characterize the Mars ionospheric state and variability sufficiently to determine its likely disruptive effect on communications and positioning						✓		✓	✓
	II.E: characterize the environment of penetrating ions (>10 MeV/nuc) at 1.38-1.62 AU.									✓

Case 4: Threshold

MOSAIC

Mini Mothership | **3 x Areo Platforms**

Science & Exploration Goals	Scientific Objectives	Investigations:	1. Ice distribution	2. Atmosphere structure	3. Atm. Diurnal behavior	4. Thermosphere	5. Ionosphere	6. Exosphere, neutral escape	7. Plasma & ion escape	8. Space weather
I. Understand Mars's present day climate processes and their inter-connections, from the sub-surface to the solar wind	~~I.A: Characterize volatile cycling between the subsurface, surface and atmospheric reservoirs.~~			✓	✓					
	I.B: Characterize the structure and ~~dynamics~~ of the Martian lower-middle atmosphere on meso- and global scales, and its geographic, diurnal, and seasonal variability.			✓	✓					
	~~I.C: Correlate variability in the thermosphere, ionosphere, and escape rates to:~~	~~The lower-middle atmosphere.~~		✓	✓					
		~~The space weather environment~~								✓
	~~I.D: Characterize fields and plasma flows in the upstream solar wind and throughout the magnetosphere and upper ionosphere, separating spatial from temporal variability.~~									✓
II. Identify hazards, characterize resources, and demonstrate technologies to enable the Human Exploration of Mars	~~II.A: Characterize potentially extractable water ice resources to support in situ resource utilization~~									
	II.B: Characterize the Mars atmospheric state with sufficient spatial sampling and cadence to allow accurate data assimilation and weather forecasting.			✓	✓					
	~~II.C: characterize neutral winds in the mesosphere and lower thermosphere (60 km-130 km) and their variability with lower atmospheric conditions and solar activity.~~									
	~~II.D: Characterize the Mars ionospheric state and variability sufficiently to determine its likely disruptive effect on communications and positioning~~									✓
	II.E: characterize the environment of penetrating ions (>10 MeV/nuc) at 1.38-1.62 AU.									✓

Backup:
MOSAIC Investigations

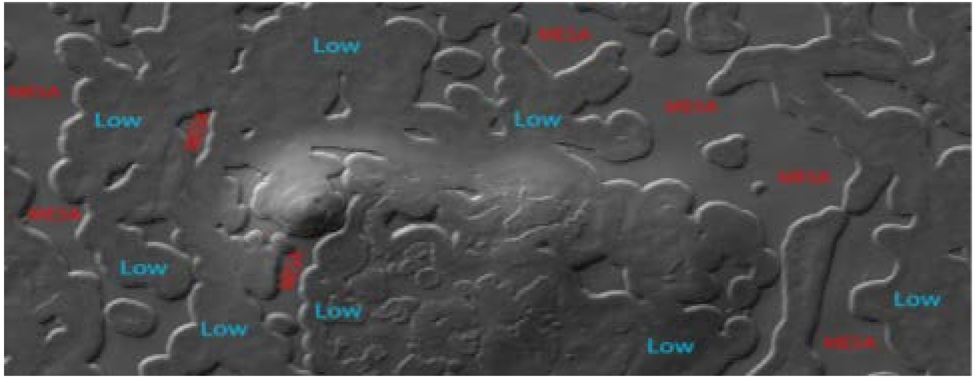
Science Investigations

MOSAIC

Investigations *	Measurements**	Instruments	Platforms
1. Measure the three-dimensional distribution of ice from the surface to 10 m below.	Subsurface ice abundance derived from dielectric constant. Surface thermal inertia Surface water ice & albedo	P-band radar with VV or HH polarization. Thermal IR imager Visible camera	Mothership
2. Measure the geographic and altitude distribution of pressure, winds, aerosol concentrations, water vapor, ozone, and temperatures in the Mars lower and middle atmosphere.	Vertical profiles (0-80 km) of: temperature, winds, dust, H_2O and CO_2 ices, H_2O vapor, O_3. Surface temperature and pressure.	Microwave/sub-mm limb and nadir sounder Thermal infrared spectrometer/radiometer Near-infrared spectrometer LIDAR	Mothership
3. Measure the complete diurnal and geographic behavior of the atmosphere and evolution of Martian dust and ice clouds.	Visible and/or UV imagery of clouds/hazes Column opacities/abundances of dust, H_2O, ozone, and CO_2 ice Temp/pressure profiles 0 - 40 km	Visible and/or UV imager NIR spectrometer Thermal infrared spectrometer Radio Occultation	Areo-stationary
	Vertical profiles (0-80 km) of temperature, dust, H_2O and CO_2 ices, H_2O vapor.	Thermal infrared spectrometer/radiometer	Polar orbiting smallsats
4. Measure the global 3-D composition, structure, and winds in Mars's thermosphere.	Vertical profiles (90 - 200 km) of: Horizontal wind velocity Density and temp. of O, CO, N2, CO2	Wind interferometer FUV/MUV Spectrograph	Mothership
5. Measure the global 3-D structure of Mars ionosphere.	Vertical profiles (90-400 km) of electron density electron temperature CO2+ density	Radio Occultation	All orbiters
		Langmuir probe	Elliptical
		FUV/MUV Spectrograph	Mothership
6. Measure the 3-D density and temperature structure of Mars's hydrogen and oxygen exospheres.	Vertical profiles (200 - 30,000 km) of: density and temperature H density and temperature	FUV Spectrograph with hydrogen absorption cell.	Areostationary and/or Mothership
7. Measure (from multiple viewpoints) magnetic field and topology and fluxes of light and heavy ions across Mars's bow shock, through magnetosheath, down magnetotail, and into and out of the Martian upper atmosphere and ionosphere.	Magnetic field Suprathermal electron pitch angle distributions → magnetic topology Ion mass, energy, and angular distributions. Thermal electron temperature and density.	Magnetometer Electron analyzer Ion mass analyzer Langmuir probe	Elliptical
8. Measure magnetic field and plasma conditions in the upstream solar wind, and solar extreme ultraviolet irradiance.	Magnetic field Solar wind density, speed, temp. Solar EUV irradiance Solar Energetic Particle Flux	Magnetometer Solar Wind Ion analyzer Solar EUV monitor Solid State Telescope	Long Orbit

Investigation 1: Ice (subsurface & surface)

Investigations	Measurements	Instruments	Platform
1. Measure the three-dimensional distribution of ice from the surface to 10 m below.	• Subsurface ice abundance derived from dielectric constant. • Surface thermal inertia • Surface water ice & albedo	• *P-band radar with VV or HH polarization.* • *Thermal IR imager* • *Visible camera*	Near-polar low altitude circular orbit.



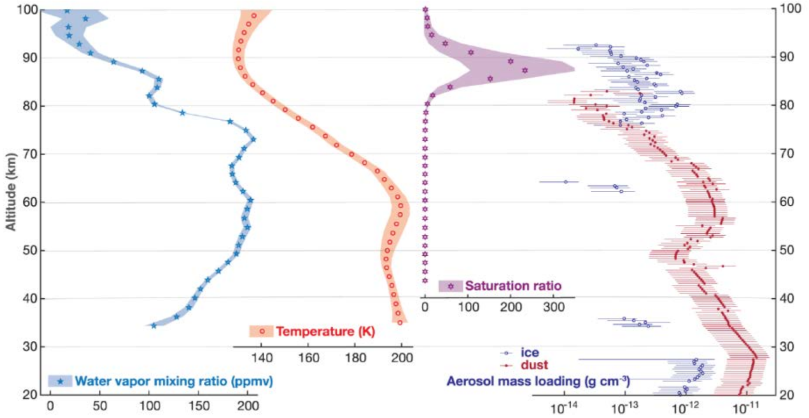
Leads: **T. Harrison, C. Stuurman**, C. Neish, I. Smith, G. Osinski,, S. Spencer.

Strong overlap with MORIE.

Investigations 2 & 3: lower-middle atmosphere

MOSAIC

Investigations	Measurements	Instruments	Platforms
2. Measure the geographic and altitude distribution of pressure, **winds**, aerosol concentrations, water vapor, ozone, and temperatures in the Mars lower and middle atmosphere.	Vertical profiles (0-80 km) of: temperature, winds, dust, H_2O and CO_2 ices, H_2O vapor, O_3. Surface temperature and pressure.	Microwave/sub-mm limb and nadir sounder Thermal infrared spectrometer/radiometer NIR spectrometer Wind LIDAR	Near-polar low altitude circular orbit.



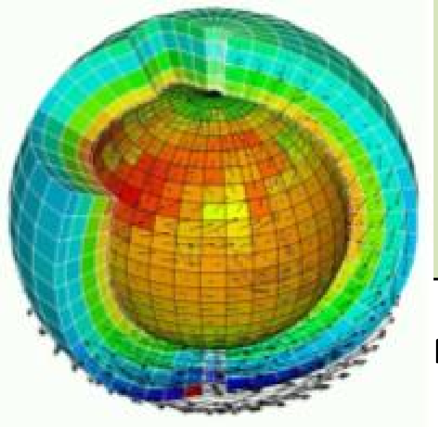
Fedorova et al., 2020

Leads: **L. Montabone, S. Guzewich**

M. Kahre, N. Heavens, M. Smith, A. Spiga, M. Mischna, M. Wolff, A. Kleinboehl, D. Hinson, F. Forget, L. Tamppari, B. Cantor

Investigations 2 & 3: lower-middle atmosphere

Investigations	Measurements	Instruments	Platforms
2. Measure the geographic and altitude distribution of pressure, **winds**, aerosol concentrations, water vapor, ozone, and temperatures in the Mars lower and middle atmosphere.	Vertical profiles (0-80 km) of: temperature, winds, dust, H_2O and CO_2 ices, H_2O vapor, O_3. Surface temperature and pressure.	Microwave/sub-mm limb and nadir sounder Thermal infrared spectrometer/radiometer NIR spectrometer Wind LIDAR	Near-polar low altitude circular orbit.
3. Measure the **complete diurnal and geographic behavior** of the atmosphere and evolution of Martian dust and ice clouds.	Visible and/or UV imagery of clouds/hazes Column opacities/abundances of dust, H_2O, ozone, and CO_2 ice Temp/pressure profiles 0 - 40 km	Visible and/or UV imager NIR spectrometer Thermal infrared spectrometer Radio Occultation	Areo-stationary
	Vertical profiles (0-80 km) of temperature, dust, H_2O and CO_2 ices, H_2O vapor.	Thermal infrared spectrometer/radiometer	Near-polar low altitude circular @ different local times



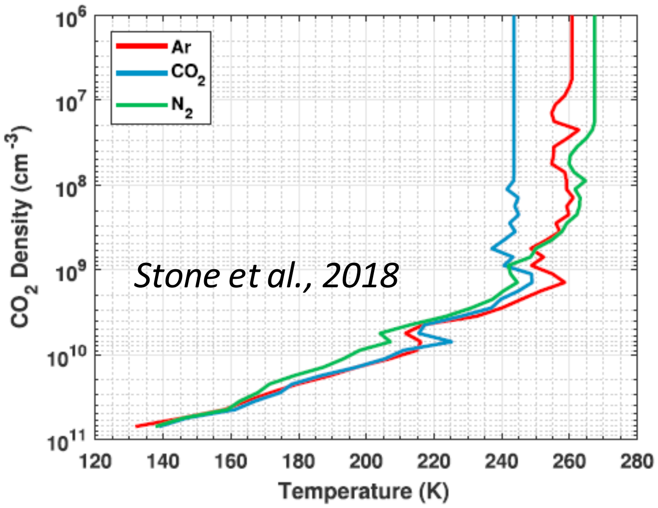
Leads: **L. Montabone, S. Guzewich**

M. Kahre, N. Heavens, M. Smith, A. Spiga, M. Mischna, M. Wolff, A. Kleinboehl, D. Hinson, F. Forget, L. Tamppari, B. Cantor

Investigations 4 & 5: Thermosphere-Ionosphere

MOSAIC

Investigations	Measurements	Instruments	Platforms
4. Measure the global 3-D composition, structure, and **winds** in Mars's thermosphere.	Vertical profiles (60 - 200 km) of: -Horizontal wind velocity -Density and temp. of O, CO, N_2, CO_2	Wind interferometer FUV/MUV Spectrograph	Near-polar low altitude circular orbit.

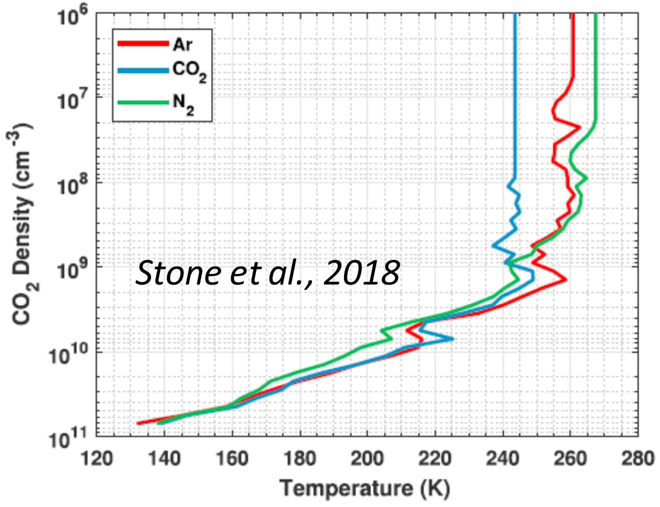


Stone et al., 2018

Thermosphere
Lead: **S. England**
J. Deighan, S. Bougher, A. Brecht

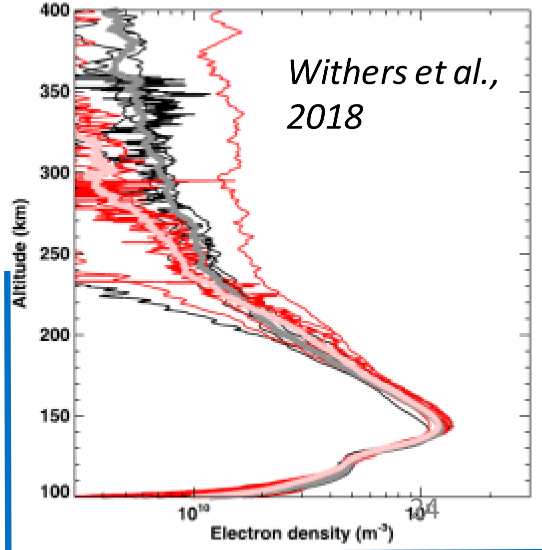
Investigations 4 & 5: Thermosphere-Ionosphere

Investigations	Measurements	Instruments	Platforms
4. Measure the global 3-D composition, structure, and winds in Mars's thermosphere.	Vertical profiles (60 - 200 km) of: -Horizontal wind velocity -Density and temp. of O, CO, N_2, CO_2	Wind interferometer FUV/MUV Spectrograph	Near-polar low altitude circular orbit.
5. Measure the global 3-D structure of Mars ionosphere.	Vertical profiles (90-400 km) of Electron density	Radio Occultation	Elliptical+polar
		Langmuir probe	Elliptical orbit



Ionosphere
Lead: **P. Withers**
R. Lillis, D. Andrews, M. Paetzold, S. Tellmann, K. Peter, M. Lester, C. Fowler, B. Sanchez-Cano

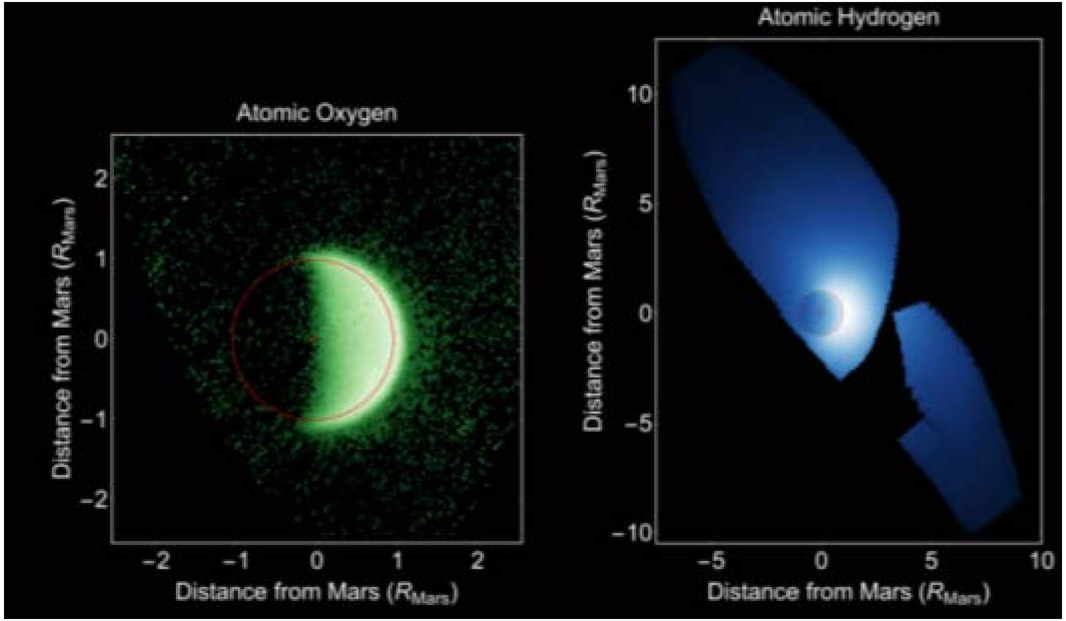
Thermosphere
Lead: **S. England**
J. Deighan, S. Bougher, A. Brecht



Investigation 6: exosphere

Investigations	Measurements	Instruments	Platforms
6. Measure the 3-D density and temperature structure of Mars's hydrogen and oxygen exospheres.	Vertical profiles (200 - 30,000 km) of: density and temperature H density and temperature	FUV Spectrograph.	Areostationary

Team members:
M. Chaffin, J. Deighan

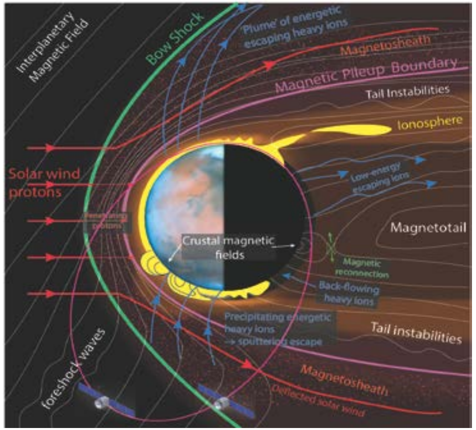


Investigations 7&8: Magnetosphere & Escape

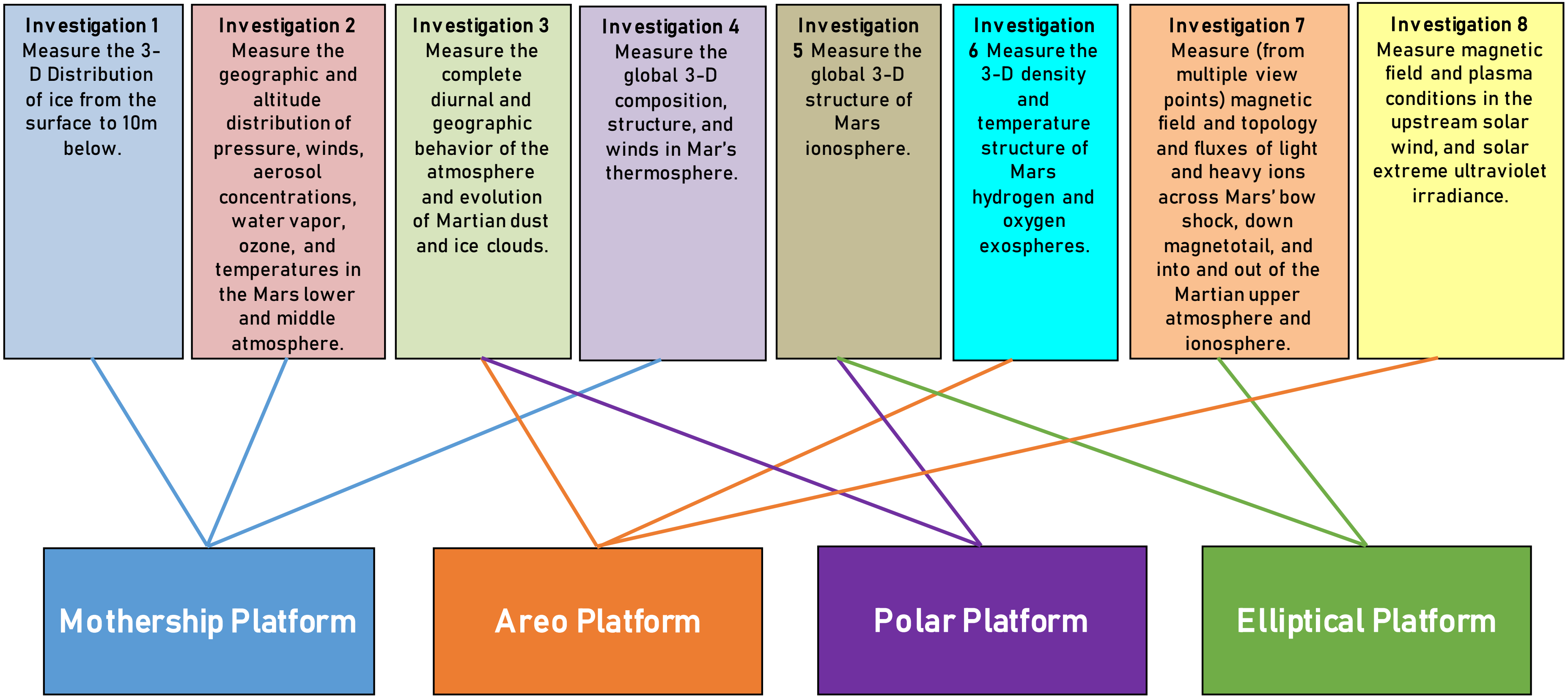
MOSAIC

Investigations	Measurements	Instruments	Platforms
7. Measure magnetic field strength & topology and fluxes of light and heavy ions across Mars's bow shock and throughout the magnetosphere, from **multiple simultaneous locations**.	Magnetic field Suprathermal electron pitch angle distributions → magnetic topology Ion mass, energy, and angular distributions. Thermal electron temperature and density.	Magnetometer Electron analyzer Ion mass analyzer Langmuir probe	Elliptical orbit ~150km x ~6000 km
8. Measure magnetic field and plasma conditions in the upstream solar wind, and solar extreme ultraviolet irradiance.	Magnetic field Solar wind density, speed, temp. Solar EUV irradiance Solar Energetic Particle Flux	Magnetometer Solar Wind Ion analyzer Solar EUV monitor Solid State Telescope	Outside Mars' bow shock

Magnetosphere/Escape
Lead: **S. Curry**
J. Luhmann, **R. Lillis,** F. LeBlanc, J. Halekas, D. Brain, X. Fang, J. Espley, H. Opgenoorth, O. Vaisberg



Connections between science and architectures



Backup: MOSAIC Orbital Platforms

Science drives mission architecture

MOSAIC

1 **INVESTIGATION 1**
Ice Distribution
Measure the 3-D Distribution of ice from the surface to 10m below.

2 **INVESTIGATION 2**
Atmosphere Structure
Measure the geographic and altitude distribution of pressure, winds, aerosol concentrations, water vapor, ozone, and temperatures in the Mars lower and middle atmosphere.

3 **INVESTIGATION 3**
Atmosphere Diurnal Behavior
Measure the complete diurnal and geographic behavior of the atmosphere and evolution of Martian dust and ice clouds.

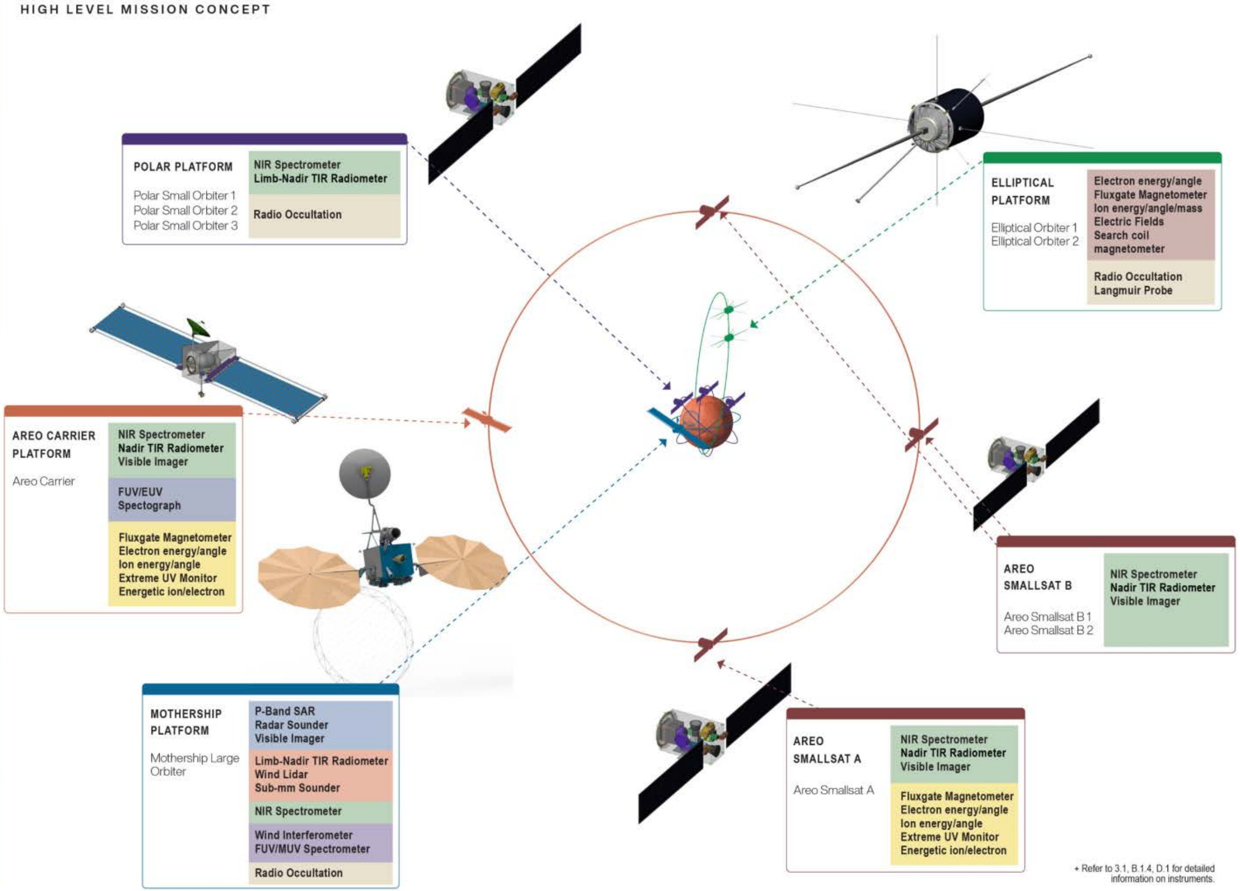
4 **INVESTIGATION 4**
Thermosphere
Measure the global 3-D composition, structure, and winds in Mar's thermosphere.

5 **INVESTIGATION 5**
Ionosphere
Measure the global 3-D structure of Mars ionosphere.

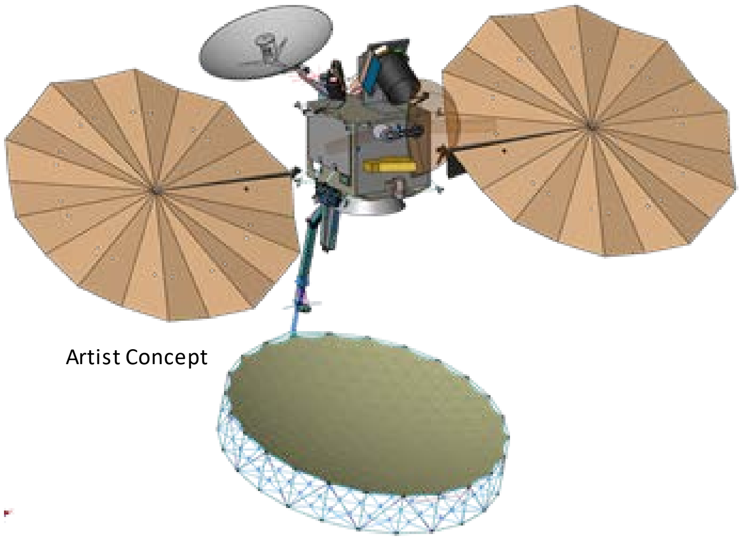
6 **INVESTIGATION 6**
Exosphere / Neutral Escape
Measure the 3-D density and temperature structure of Mars hydrogen and oxygen exospheres.

7 **INVESTIGATION 7**
Plasma / Ion Escape
Measure (from multiple viewpoints) fluxes of light and heavy ions, magnetic field and topology, plasma waves, and electric fields within and between all regions of Mars' hybrid magnetosphere.

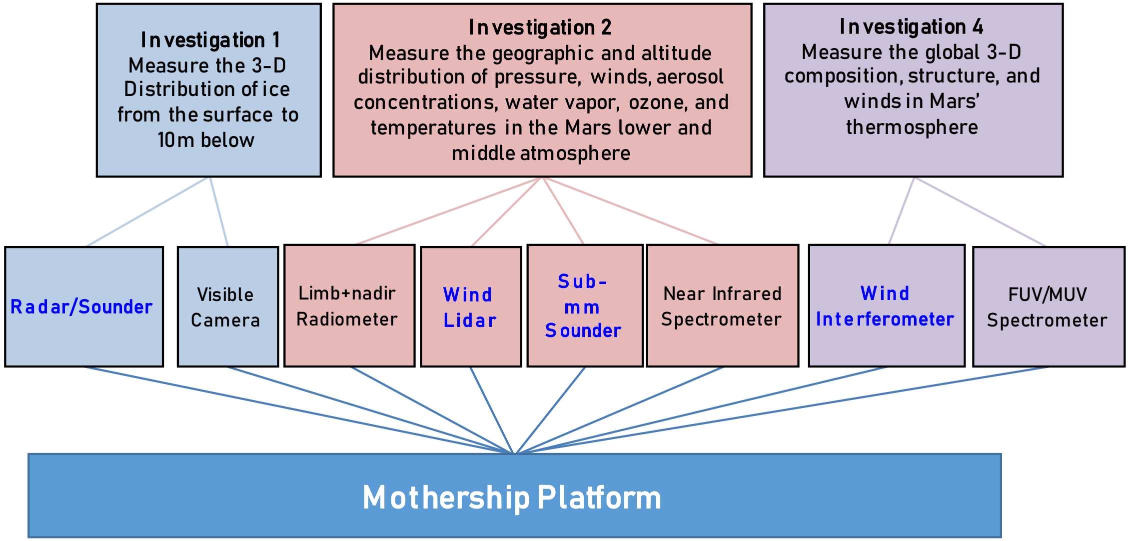
8 **INVESTIGATION 8**
Space Weather
Measure magnetic field and plasma conditions in the upstream solar wind, and solar extreme ultraviolet irradiance.



Mothership Platform



Artist Concept



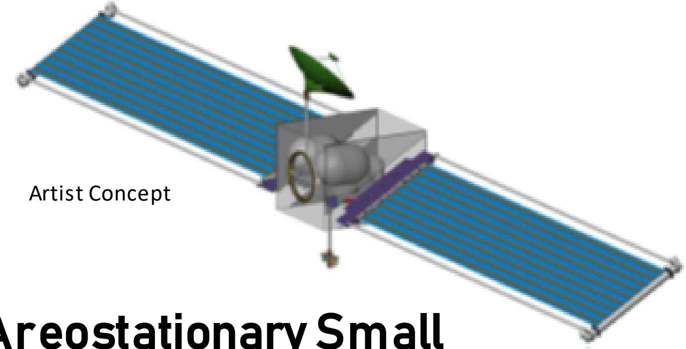
Solar Electric Large Orbiter

(1) Orbiter Spacecraft

Wet Mass: 3721 kg

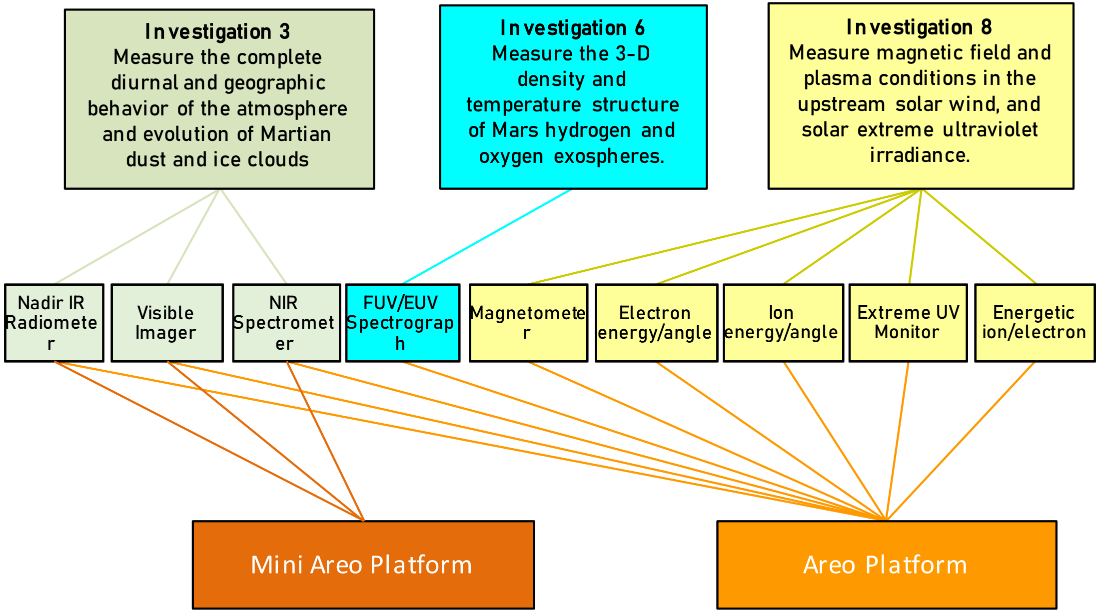
Orbit: 300 km; ~93° (MRO Orbit)

Areostationary Platform



Artist Concept

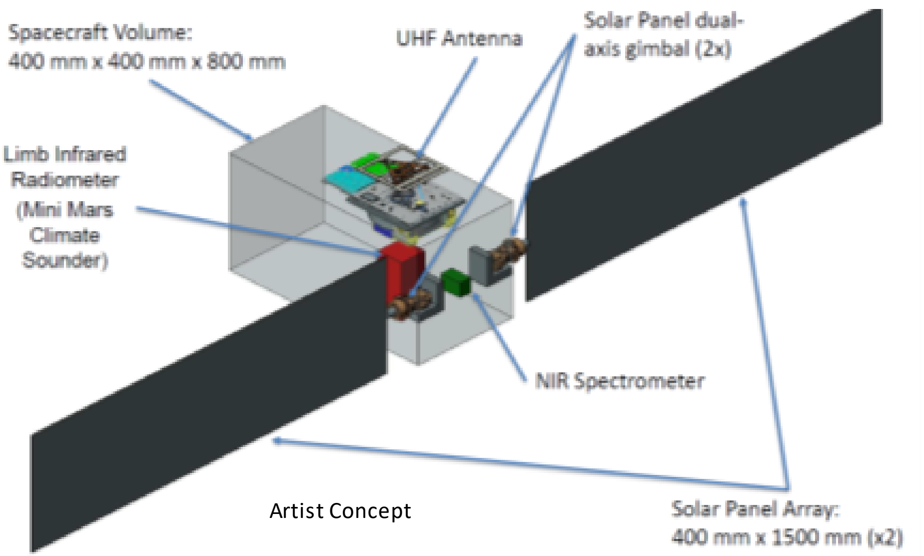
Areostationary Small Orbiter
(1) Orbiter Spacecraft
Wet Mass: 565 kg
Orbit: 17,000 km; Equatorial



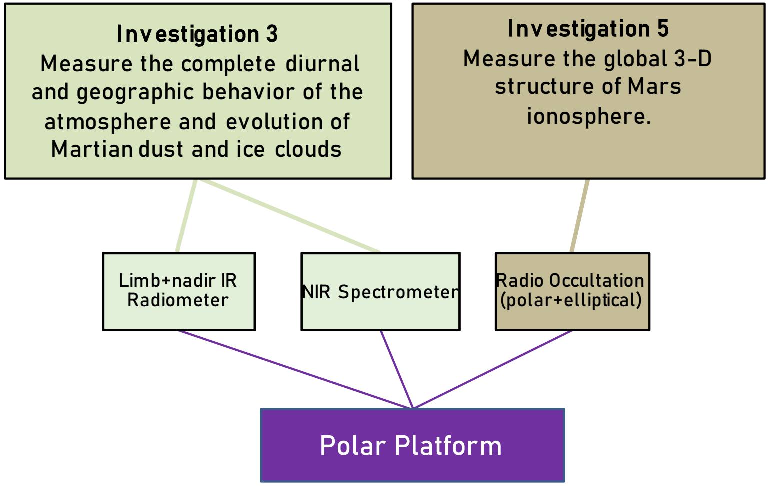
Artist Concept

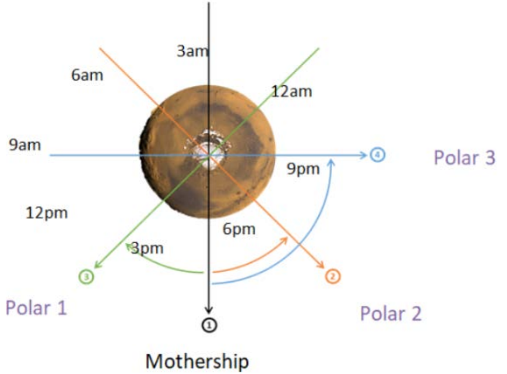
Mini Areostationary Orbiter
(3) Orbiter Spacecraft
Wet Mass: 93 kg
Orbit: 17,000km; Equatorial

Polar Platform



Artist Concept





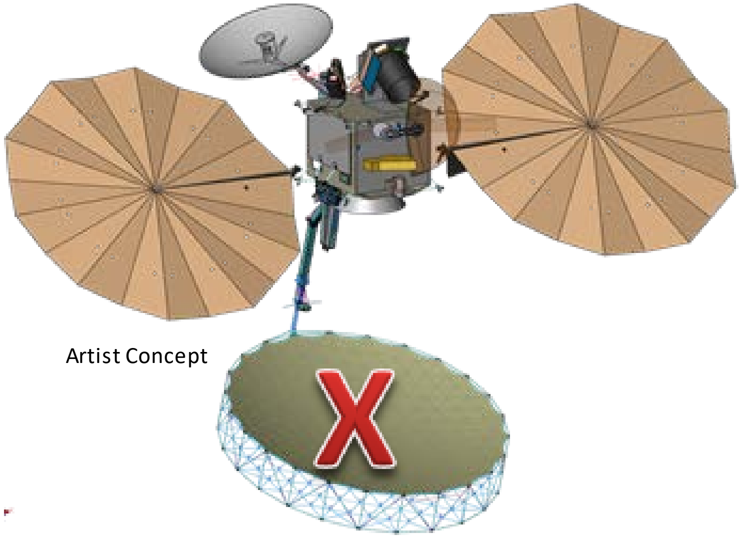
Polar Small Spacecraft

(3) Orbiter Spacecraft

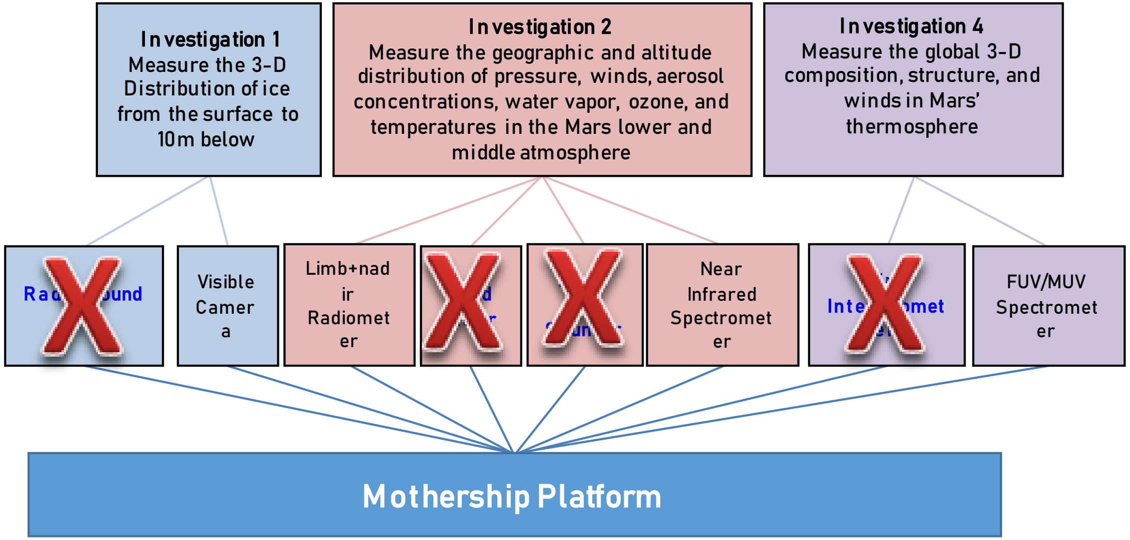
Wet Mass: 93 kg

Orbit: 300 km; ~93° (MRO Orbit)

“Mini” Mothership Option



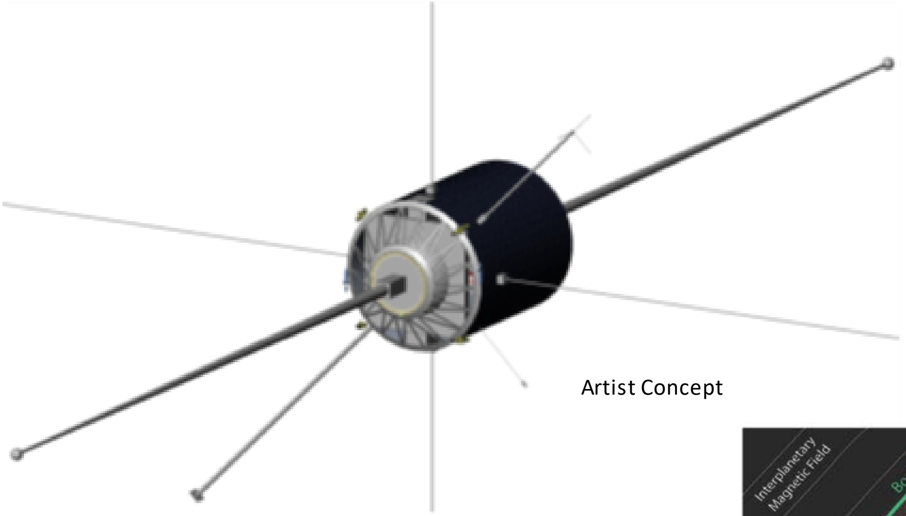
Artist Concept



Solar Electric Small Orbiter
(1) Orbiter Spacecraft
Wet Mass: ~3700 → ~750 kg
Orbit: 300 km; ~93° (MRO Orbit)

- **Huge reduction** in mass and cost
- **Preserves**: global coverage of atmospheric connections
- **Sacrifices**: brand-new measurements (ice and wind)

Elliptical Platform



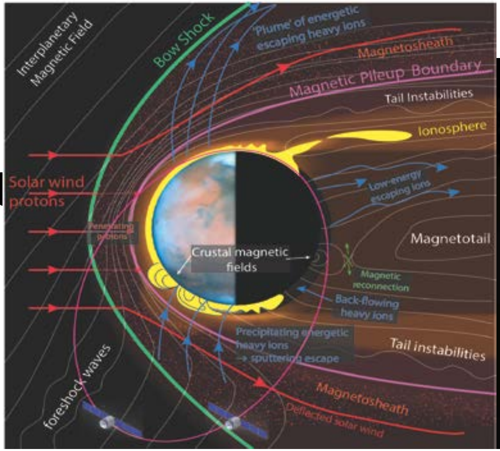
Artist Concept

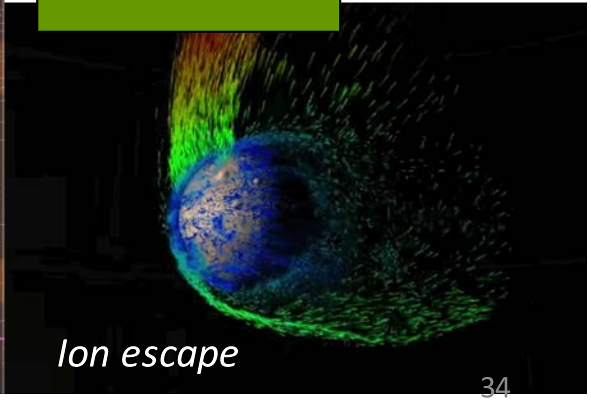
Investigation 5
Measure the global 3-D structure of Mars ionosphere.

Investigation 7
Measure (from multiple view points) magnetic field and topology and fluxes of light and heavy ions across Mars' bow shock, down magneto tail, and into and out of the Martian upper atmosphere and ionosphere

- Radio Occultation
- Langmuir Probe
- Electric Fields
- Electron energy/angle
- Ion energy/angle /mass
- Magnetometer

Elliptical Platform



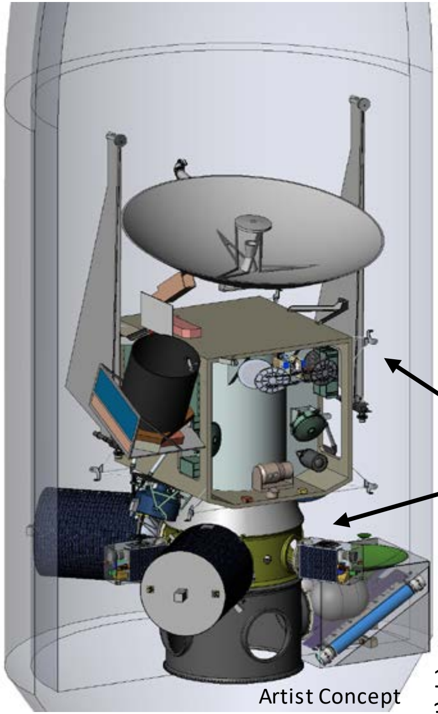


Elliptical Small Spinning Spacecraft
(2) Orbiter Spacecraft
Wet Mass: 221 kg
Orbit: 150 x 6000 km; 75°

MOSAIC Architecture

MOSAIC

MOSAIC By the Numbers



Artist Concept

10 Spacecraft Elements

49 Science Instruments

3 Orbital Perspectives

1 Launch Vehicle

1 – Large Orbiter

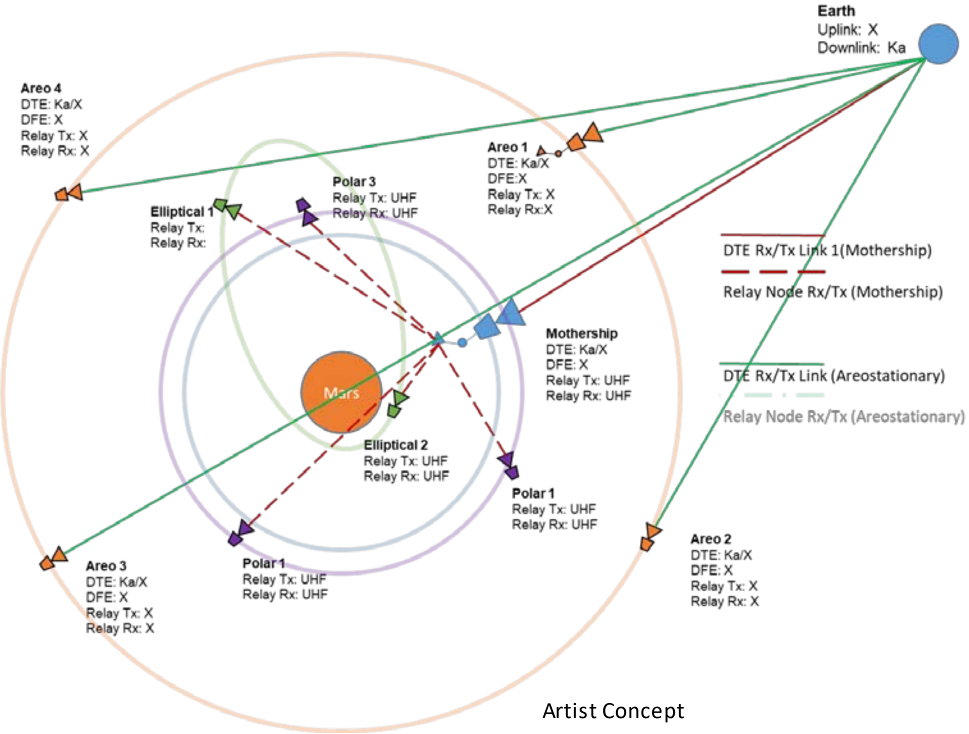
2 - Elliptical ESPA-Class S/C

3 - Polar ESPA-Class S/C

1 - Areostationary ESPA Class

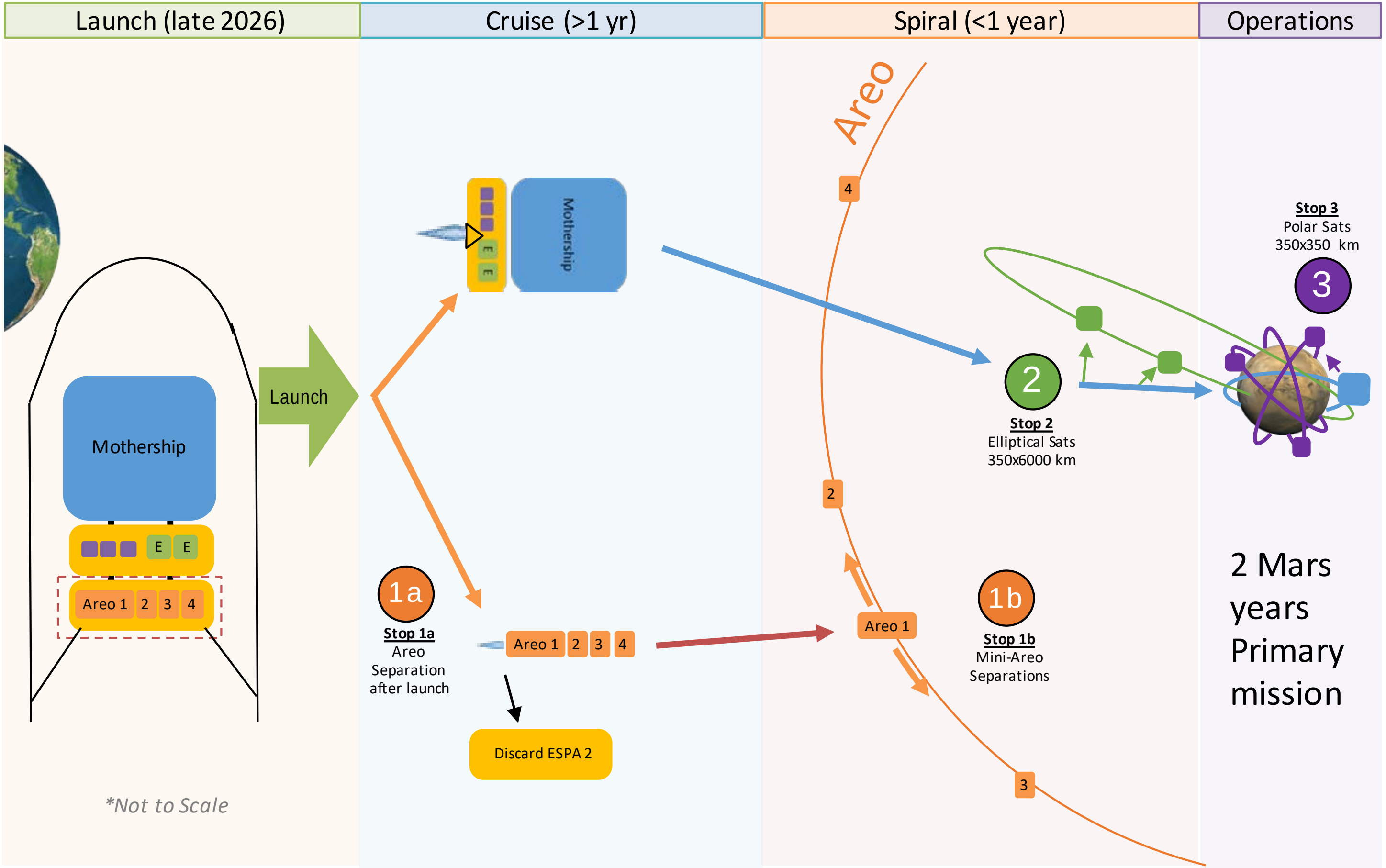
3 – Small Areostationary S/C

MOSAIC Telecommunications Architecture



Artist Concept

Constellation Delivery (Example Option)



Backup: MOSAIC Relevance and Rationale

MOSAIC Science Impact

Simultaneous measurements of all "regions" of the climate system will:

- Characterize geographic, diurnal, mesoscale, and seasonal behavior.
- Lead to groundbreaking improvements in our understanding of how climate variables correlate with one another.
  - I.e. uncover how different parts of the climate system "talk" to each other.
- Spur understanding of the physical processes occurring within and between regions.

To examine off-line: MOSAIC "improvement matrix" →

Charcterizing the effect of ↓ on →:			Ice		Lower Atmosphere structure				Thermo-sphere			Iono-sphere			Exosphere		Magnetosphere		Space weather drivers			
MOSAIC will enable, w.r.t. current/planned observations: Groundbreaking improvement / Significant Improvement / Incremental Improvement		Characterized alone?	Shallow Subsurface	Surface	Temp, pressure	Dust	H2O (a) /condensates	Wind /dynamics	Temp, pressure	Composition	Wind/dynamics	Temp, density	Composition	Dynamics	Structure	Dynamics/ Neutral escape	E, B Fields	Flows & ion escape	Solar wind	IMF	Solar EUV	Energetic Particles
Ice	Shallow subsurface	B		B	P	P	B															
	surface	I	B		B	B	I	P														
Lower Atmo-sphere	Temp, pressure	I	B	I		I	I	B	B	B	P	B	B	P	B	B	P	P				
	Dust	I	P	B	I		B	P	B	B	P	B	B	P	B	B	P	P				
	H_2O/condensates	B	P	B	I	I		P	B	B	P	B	B	P	B	B	P	P				
	Wind/dynamics	P		P	P	P	P		P	P	P	P	P	P	P	P	P	P				
Thermo-sphere	Temp, pressure	I								I	P	I	I	P	I	I	B	B				
	Composition	I							I		P	I	I	P	I	I	B	B				
	Wind/dynamics	P							P	P		P	P	P	P	P	P	P				
Iono-sphere	Temp, density	I									P		B	B	B	B	B	B				
	Composition	I									P	I		B	B	B	B	B				
	Dynamics	B							B		P	B	B		B	B	B	B				
Exosphere	Structure	I										I	I	B		B	B	B				
	Dynamics/ Neutral Escape	B										B	B	B	B		B	B				
Magnetosphere	E, B fields	I							B	B	P	B	B	B	B	B		B				
	Flows & ion escape	I							B	B	P	B	B	B	B	B	B					
Space weather drivers	Solar wind	M							B	B	P	B	B	B	B	B	B	B				
	IMF	M							B	B	P	B	B	B	B	B	B	B				
	Solar EUV	M							I	I	P	I	I	P	I	B	B	B				
	Energetic Particles	M					P		B	B	P	B	B	P								

Current degree of understanding enabled by available measurements:	(M) Mature: Mostly Well-understood	(I)Incomplete: at least one important aspect not understood	(B) Basic understanding but many issues remain	(P) Poor understanding and/or based solely on models.	Negligible direct connection expected

First systematic observations of shallow subsurface material properties

Areostationary observations

First systematic lower atmosphere wind measurements

High-res observations of aerosols and water vapor

MAVEN measurements exist

First systematic thermosphere wind measurements

Radio occultation + multi-point in situ ionosphere measmts.

total ionospheric density only.

$T_{exosphere}$ and continuous monitoring

Coordinated 2-point plasma measurements

Real-time solar wind & IMF monitoring.

Why MOSAIC?

MEPAG. Goal II "Understand the processes and history of climate on Mars":

- ***A1.*** *Constrain the processes that control the present distributions of dust, water, & carbon dioxide in the lower atmosphere, at daily, seasonal & multi-annual timescales.*
- ***A2.*** *Constrain the processes that control the dynamics & thermal structure of the upper atmosphere & surrounding plasma environment.*
- ***A4.*** *Constrain the processes by which volatiles & dust exchange between surface & atmospheric reservoirs.*
- ***C3.*** *Determine present escape rates of key species & constrain the processes that control them.*

Mars Science Goals, Objectives, Investigations, and Priorities: 2020 Version

Mars Exploration Program Analysis Group (MEPAG)

Prepared by the MEPAG Goals Committee:

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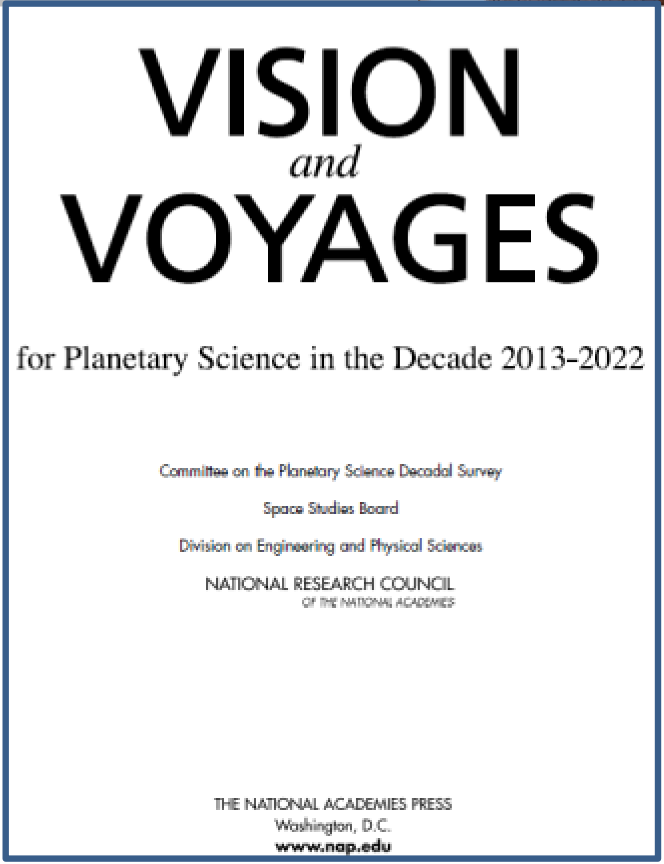
Why MOSAIC?

2013-2022 Decadal Survey calls for a mission like MOSAIC, stating:

"Fundamental advances in our understanding of modern climate would come from a ***complete determination of the three-dimensional structure of the martian atmosphere from the surface boundary layer to the exosphere.*** *This should be performed* ***globally****, ideally by combining* ***wind, surface pressure and accurate temperature*** *measurements from landed and orbital payloads."*


VISION
and
VOYAGES

for Planetary Science in the Decade 2013-2022

Committee on the Planetary Science Decadal Survey

Space Studies Board

Division on Engineering and Physical Sciences

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OF THE NATIONAL ACADEMIES

THE NATIONAL ACADEMIES PRESS
Washington, D.C.
www.nap.edu

Why MOSAIC?

Concept maturity/relationship to SAGs.

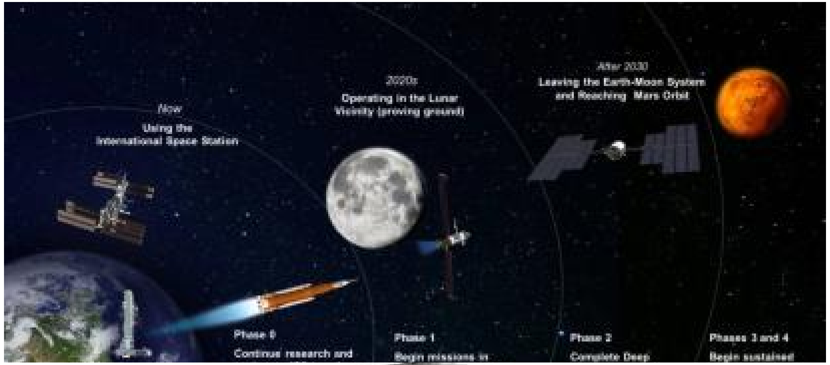
NEX-SAG and ICE-SAG outline the needed measurements in the lower-and middle atmosphere. BUT:

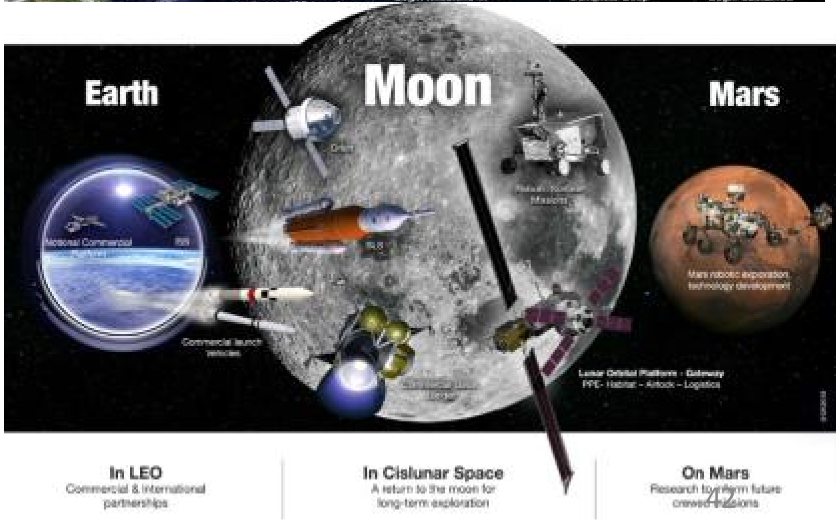
- SAGs didn't account for recent discoveries:
  - Strong relationships between lower/middle atmospheric dynamics and escape from the upper atmosphere.
  - Extreme weather in mesoscale systems.
- This concept is ***technically immature*** at present. We need to:
  - Understand the risks and challenges of flying and operating a mothership with several linked daughtercraft in the Mars environment
  - Specify the resolution and sampling frequency needed to understand extreme weather at sub-100 km scales.

Why MOSAIC?

Relevant to NASA Exploration Goals. MOSAIC fulfills ***seven*** high-priority knowledge gap-filling activities identified by PSAG:

1. ***Ice depth variation*** within the first meter (for drinking water & propellant synthesis). Activity D1-5, D1-6.
2. ***Weather forecasting***: dust climatology (B1-1), model validation (A2-1), global-scale T, wind, aerosols (A1-1, A1-2, A1-3).
3. ***Communications***: deep space optical comms (A4-2), delay-tolerant networking, and continuous relay-to-Earth from any Mars longitude.





Backup: MOSAIC Synergies with other Mars missions

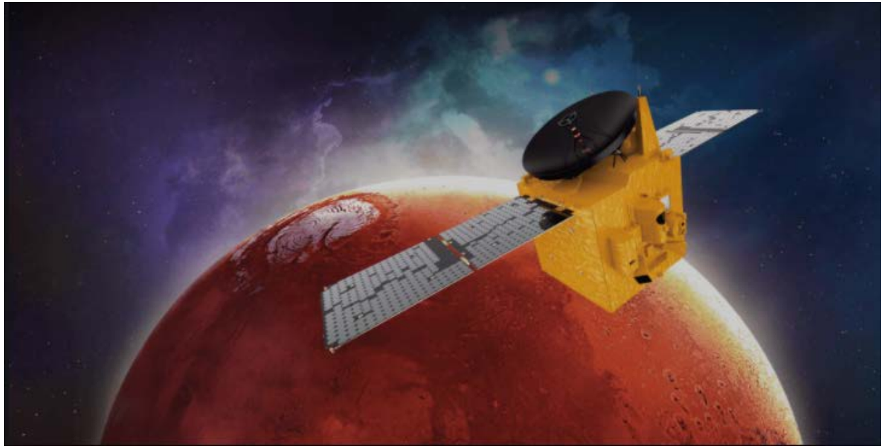
Fitting in with the Crowd: TGO

The ESA Trace Gas Orbiter:

- measures altitude profiles of H_2O, O_3, and aerosols but only at 6 AM and 6 PM (via solar occultation), providing a precursor to MOSAIC's much more systematic sub-mm limb sounding.
- conducts traditional nadir mapping of temperature profiles, ice, and aerosols, as MRO MCS has done, but takes ~55 days to cover all local times. MOSAIC will ensure full diurnal, geographic, altitude, and seasonal coverage.
- uses neutrons to derive total water ice abundance in the top ~1 m with 100-200 km resolution, i.e. complementary to the much-higher resolution, and deeper ice depth profiles from MOSAIC's radar.

Fitting in with the Crowd: EMM

- Starting in May 2021, the Emirates Mars Mission will make total column abundance/opacity measurements from a 55-hour high circular orbit.
  - no altitude info except crude temperature profiles
- As a single spacecraft, EMM will observe most of the diurnal cycle over most of the planet once every 10 days (inevitable gaps in latitude-local time space), not ***continuously*** as MOSAIC will.



Fitting in with the Crowd: MAVEN

Hopefully MAVEN is still operational in the 2028-2034 timeframe. However MAVEN, as a single spacecraft:

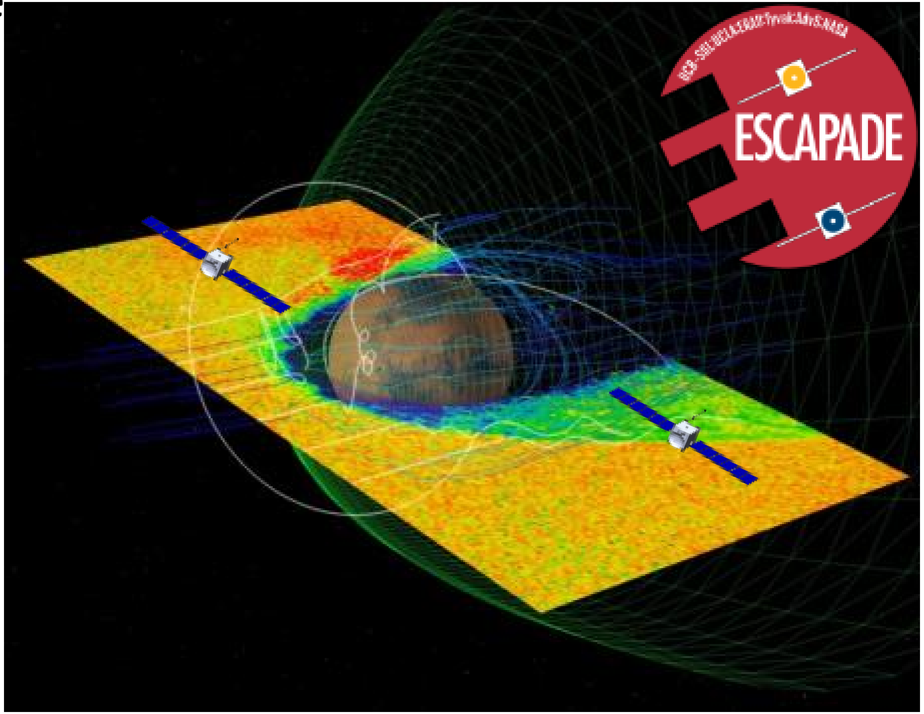
- Samples the upstream solar wind for 10s of minutes per 3.7-hour orbit on only ~40% of orbits.
- Has raised its periapsis to ~200 km in September 2020, continuing its remote FUV/MUV measurements of thermosphere density (MOSAIC Investigation 4) but no longer sampling the thermosphere or photochemical ionosphere in situ (needed for MOSAIC Investigation 5).

Fitting in with the Crowd: ESCAPADE

MOSAIC

ESCAPADE fulfills some of the science goals of MOSAIC's elliptical orbit satellites. However ESCAPADE:

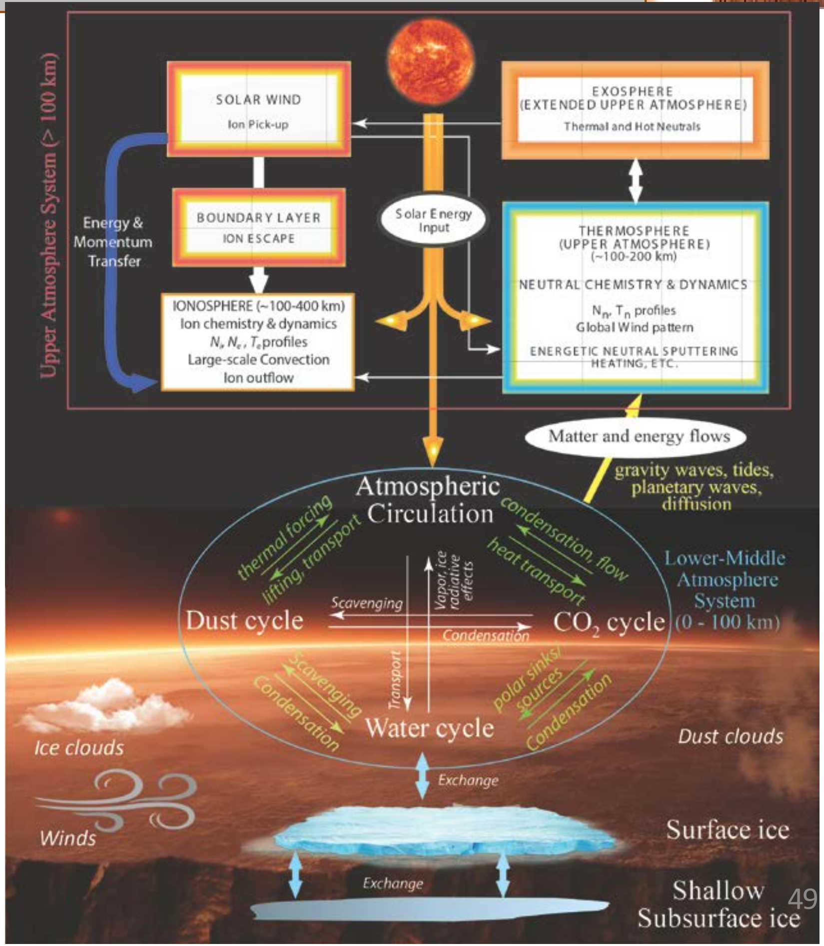
- Does not measure electric fields, which are **<u>the</u>** key factor in accelerating plasma throughout the Mars magnetosphere.
- Must pass its PDR & Confirmation Review summer 2021.
- Does not have any budget line item within HPD. Contingent on available funds.



MOSAIC Science Background

MOSAIC Motivating Questions

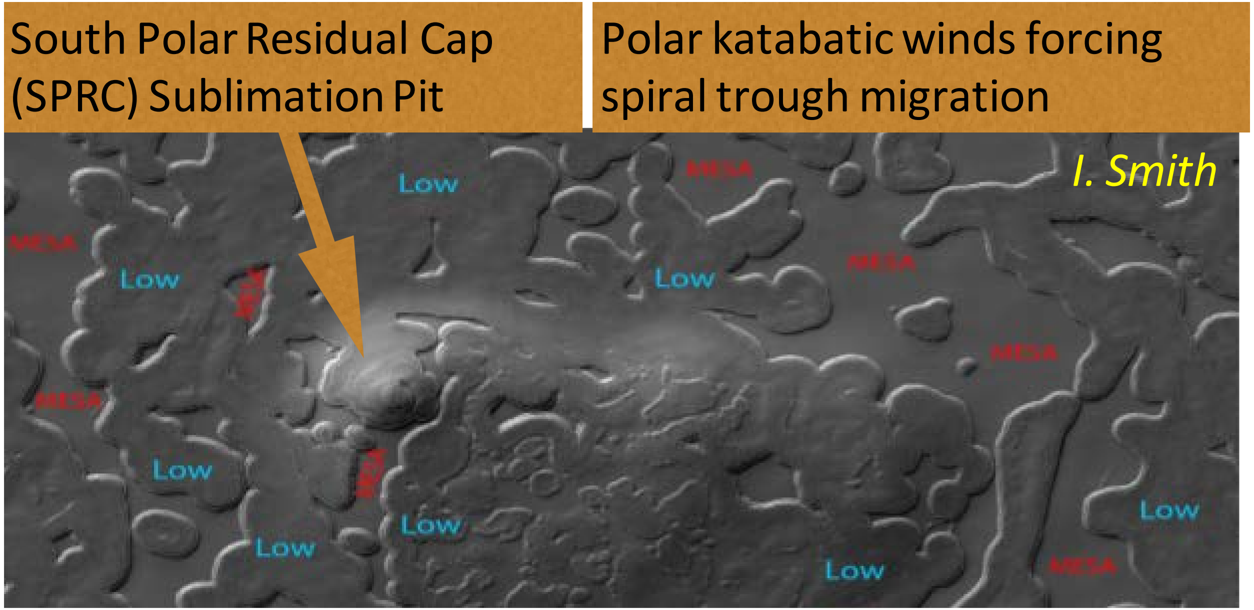
1. How do volatiles (e.g. H_2O and CO_2) move between the subsurface, surface, and atmosphere?
2. How does the Martian lower-middle atmosphere respond on meso- and global scales, to the diurnal and seasonal cycles of insolation?
3. How does coupling with the lower atmosphere combine with the influence of space weather to control the upper atmospheric system and drive atmospheric escape?



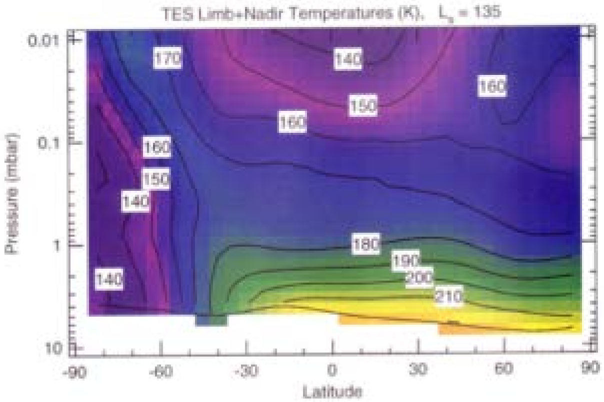
Ice-Atmosphere interactions

Numerous high latitude processes → surface pressure and distribution of ice on Mars.

- Quantification of their effects is in **its relative infancy**.
- To adequately characterize surface-atmosphere flux, need simultaneous monitoring of shallow subsurface and surface for changes, and the lower atmosphere for effects.
- SAR and thermal monitoring would detect changes that result from these interactions.

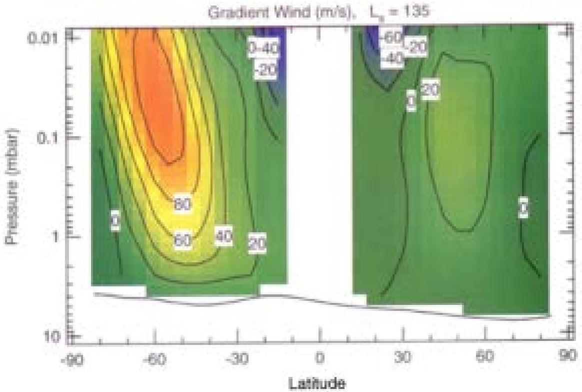


The Mysteries of Martian Winds



Knowledge of global winds is indirect: estimated from temperature measurements and the thermal wind relationship.

Malin et al. (2008)



Smith et al. (2001)

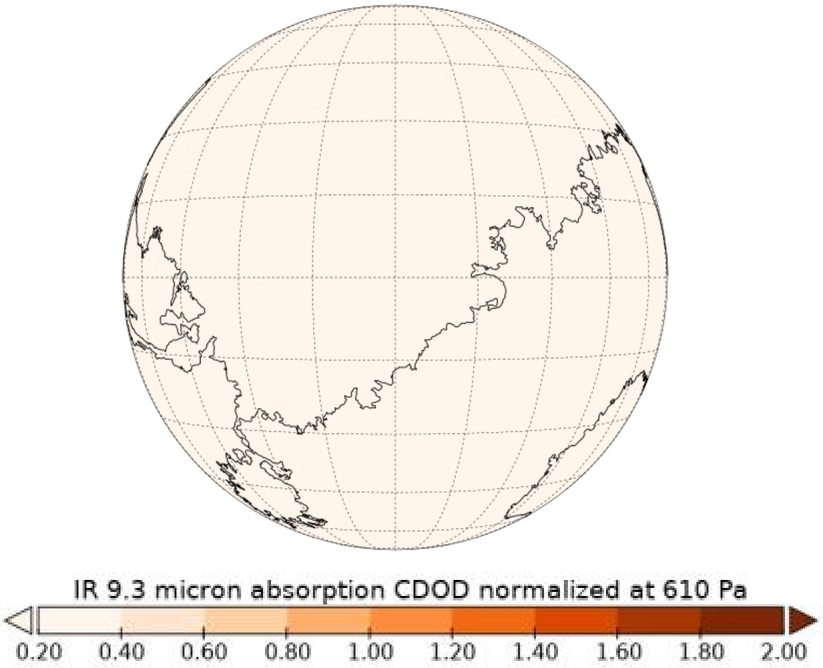
While useful to understand global dynamics, this approach is:

- inappropriate for winds in the tropics.
- too imprecise for winds in synoptic systems at all latitudes like the high-latitude low pressure systems pictured above.

Our study considered the tradeoffs of different instrumentation types for winds and other important measurable quantities (e.g. aerosols, temperatures, trace gases).

The extreme nature of Global Dust Events

Synthetic perspectives based on real observations
(equivalent to areostationary view from about 17,000 km above the equator)
Centered on 0° lon, 0° lat



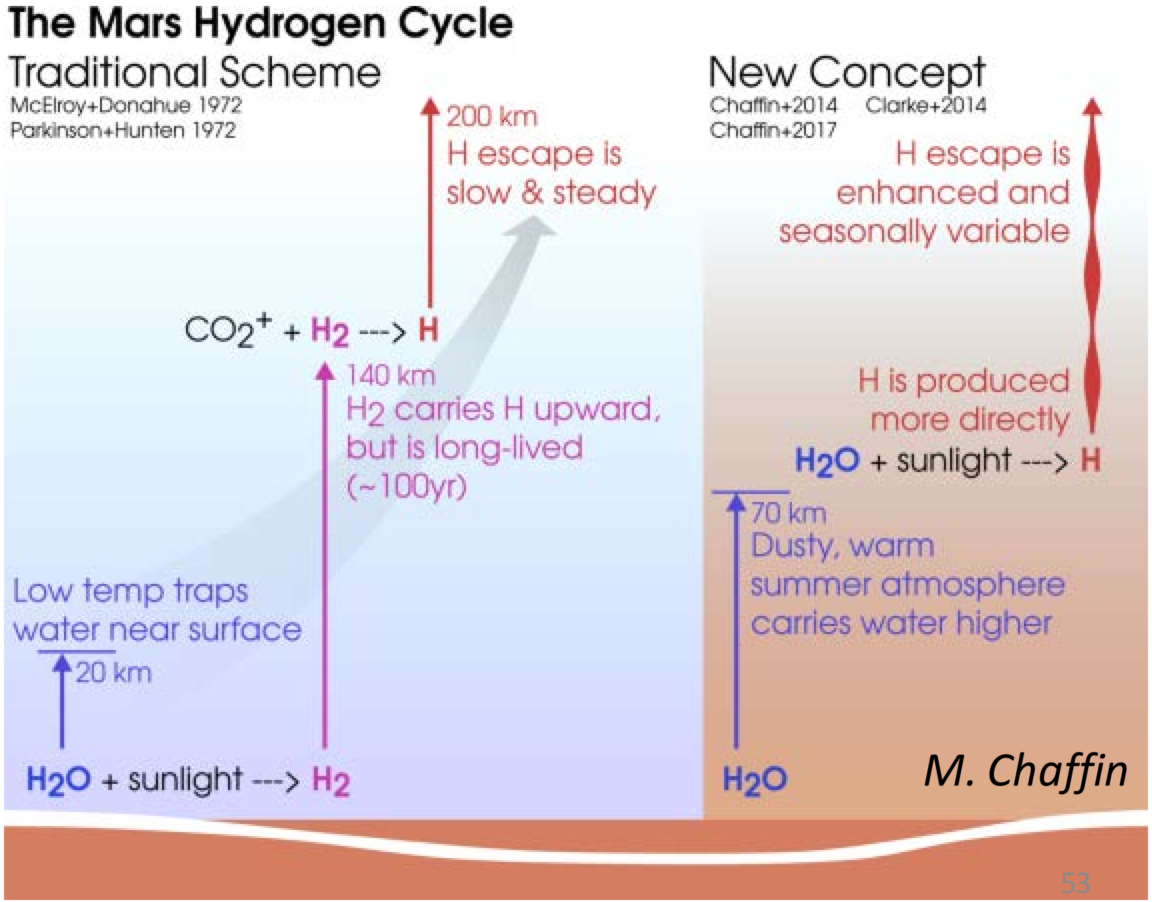
Montabone et al., 2019

Column Dust Opacity data from:
Montabone et al., JGR, 2020

Areostationary satellites provide the global perspective necessary to understand the storms

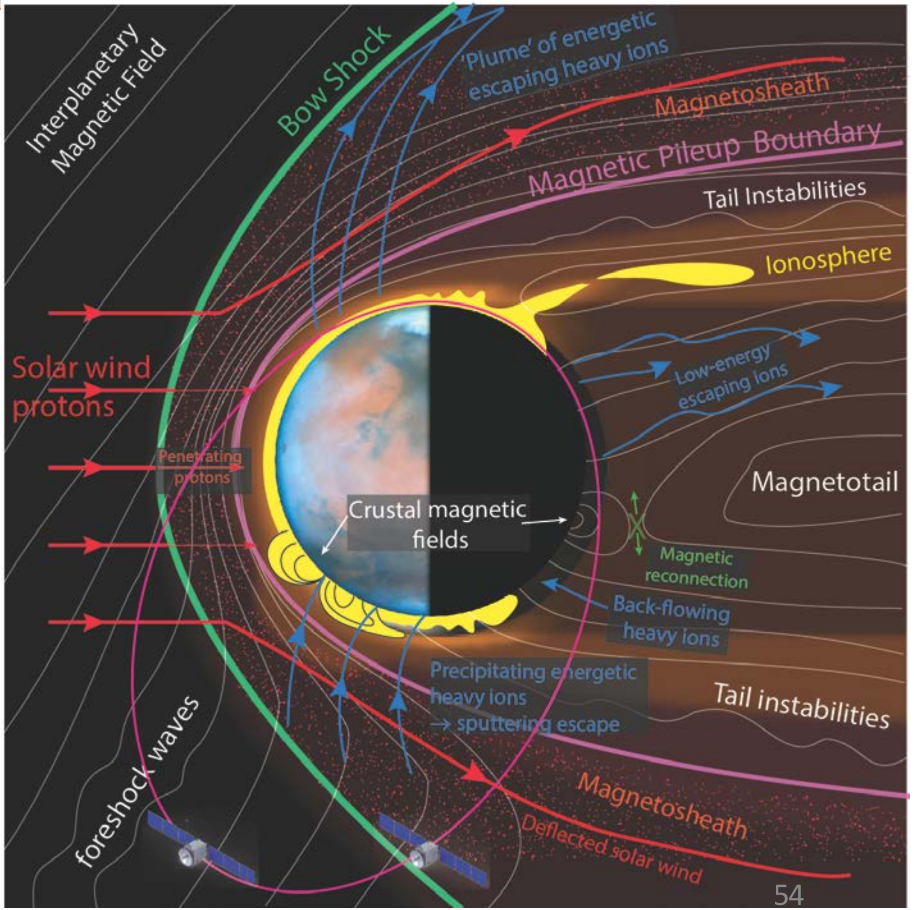
Lower/Upper Atmosphere Connections

- Measured 10-20x seasonal variability in hydrogen loss to space requires enhanced lower/upper atmosphere interchange.
- Water is observed at higher altitudes than expected, but observations are limited to the terminator (solar occultation).
- Mechanism for water transport unknown; multiple competing hypotheses.



Ionosphere-Magnetosphere & Escape

- Crustal magnetic fields create unique “hybrid” magnetosphere.
- Need coordinated multipoint in situ plasma measurements to:
  - Untangle spatial & temporal variability.
  - Measure real-time response to space weather.
  - Unravel chain of cause and effect as sun and solar wind energize ions to escape and precipitate.



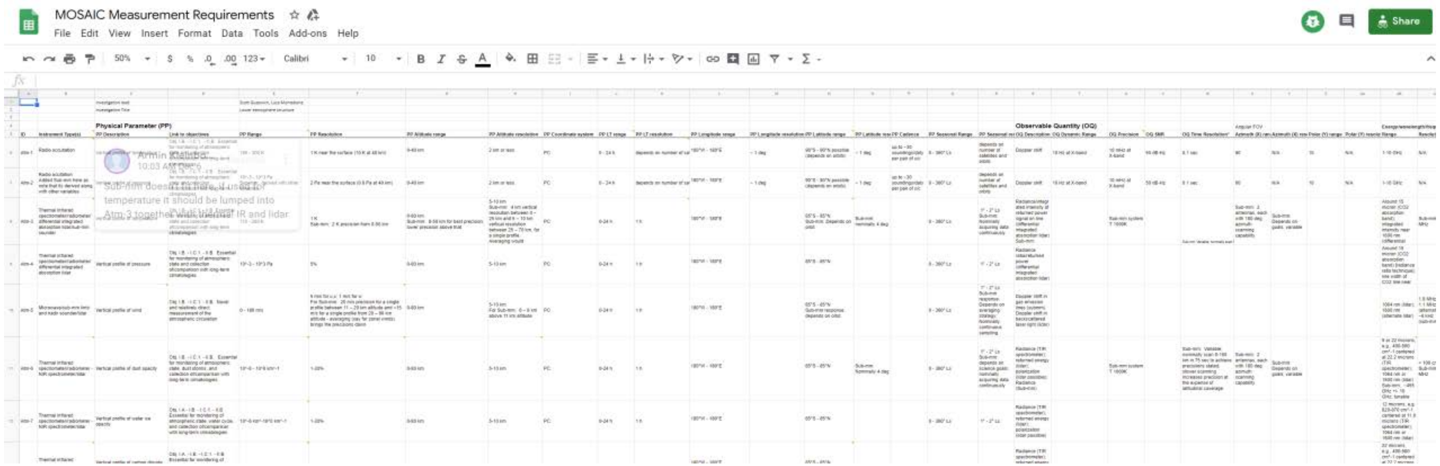
MOSAIC Concept Study Science Process

Science Requirements Definition

MOSAIC

For each investigation we defined:

- *Measurement* requirements: range, accuracy, resolution, coverage, physical parameter vs. observable quantity, baseline vs. threshold.
- *Instruments* that can meet measurement requirements.
- Example below from investigation 2:



TLDR: we compiled all the MEASUREMENT requirements in 8 spreadsheets

Instrument Requirements

MOSAIC

For each instrument we defined:

- Description, name, platform, measurements, supplier, TRL, FOV, mass, power, volume, accommodation, resolution, data rate, cost.

	Investigation	Description	Name	Platform	Measurements				Supplier	TRL	Time to TRL5	$$ to TRL5	Time TRL 5 t	$$ TRL 5 to t
21	DIU	NIR imager	Broadband InfraRed Compact, High-resolution Exploration Spectrometer (BIRCHES)	Areostationary Smallsats?	Surface pressure	CO Column	Water vapor column	Water ice/CO2 ice cover/surface hydration?	JPL/GSFC/Morehead State	6, except imaging mode (TRL 4+)				
22	THERM	FUV/MUV spectrograph	IUVS	Mothership	Altitude profiles of O thermosphere density	Thermospheric temperature profiles	Composition (CO2, O as primary target, NO nighttime as secondary goal)		LASP/SSL/SwRI	9				
23	THERM	EUV/FUV spectrograph	EMM EMUS	Mothership or Areostationary	Altitude profiles of O thermosphere density	Thermospheric temperature profiles			LASP/SSL/SwRI	9				
24	THERM	Interferometer	ICON MIGHTI	Mothership	Horizontal Wind				NRL	9				
25						Electron density irregularities (this one is hard to write) - Search for electron density irregularities with length-scale > 10 km and				~ 6 (based on the IRIS radio with modifications for smallsats and				

	FOV	Mass	Power	Volume	Requirement	range	channels	Bits per samp	Sample rate	rate (bps)	(orbit-average bps)	A-D Cost ($FY20
21	variable; we'd want the 6 degree FOV for areostat	3 kg + on-board processing-additional electronics	12-25 W + on-board processing/electronics	10x10x15 cm		1-4.3 microns	10 nm in 3 micron region; (1 to 1.8 microns with an R (λ/Δλ) of 150; 1.8 to 2.8 microns with an R of 200; and 2.8 to 4.3 microns with an R of 350	~1.25 million	0.5 s integration time in cislunar. We might want longer to collect photons.	~2 Gb single full spec	< 100 kbps	< $2 M
22	Limb (needs accurate limb tracking)	27 kg	28 W		Limb viewing 50-250 km tangent altitude	FUV:134-165nm MUV:190-300nm	FUV: 1.5 nm MUV: 2 nm	FUV: 10 Kb MUV: 20 Kb	40 integrations for FUV + MUV every 3 minutes	7 kbps	13 kbps	$30M ROM
23	Limb (needs accurate limb tracking)	15 kg	15 W									
24	Limb (needs accurate limb tracking)	40 kg	13 W		Limb view, 45 and 135 deg to ram, baffle to exclude planet, pointing control to keep FOV away from lower atmosphere, sun etc.	557.7 nm and 1.27 um	2 channels, each with 2 wavelengths, and 50 altitude elements	1.26 million	2 exposures per channel every 3 minutes	10 kbps	14 kps orbit av	$40M (without reserves)
25	antenna boresight in velocity and anti-velocity direction: +/- 60 deg in azimuth,					UHF/L/S-band			1 kHz (plus			

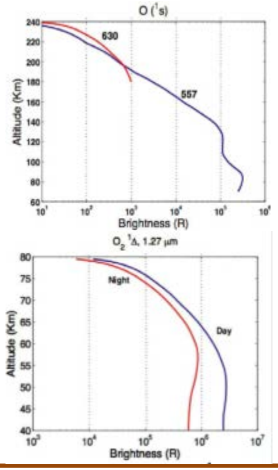
TLDR: we compiled lots of INSTRUMENT requirements to guide the JPL concept study team

Quad chart example: NIR, Visible Doppler Interferometer

Middle-Upper Atmosphere Winds

- Knowledge gap in dynamics – especially between homopause and near exobase.
- Winds reveal global-scale dynamics, large-sale waves, provides inputs to models.

MOSAIC Objectives: I.C, II.C



Resources/accommodations

Platform (order)	M
# platforms	Baseline: 1
Mass	40 kg (for both channels
Power (incl. heat)	20 W ave. (heat est.)
Data Rate	Baseline: 14 kbps (number already accounts for duty cycling of 2 images per 3 min)
FOV	3°H x 5°V x 2 channels, 45° and 135° to ram
Limb Pointing (deg)	Contrl: 0.1, Know: 0.05, Jitter., 0.06 over 30s
Keep out zones.	No sun in FOV while on. Baffle scatter below ~50km
Conops.	Always on, 2x30s exp per 3 min

Measurement Requirements

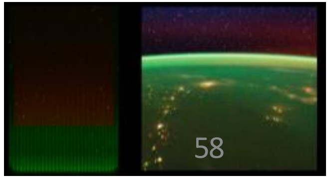
Physical Parameter/ Observable Quantity	Doppler shift of O(¹S) (557.7 nm)	Doppler shift of O_2 1Δ (1.27 μm)
Altitude range	80-150 km⁺	60-80 km
Altitude resolution	5 km⁺⁺	2.5 km⁺⁺
Precision - f(alt)	10-20 m/s	5-10 m/s
Cadence	3 minutes	3 minutes

⁺Daytime only

⁺⁺Must be ½ scale height or better

TRL story/development required

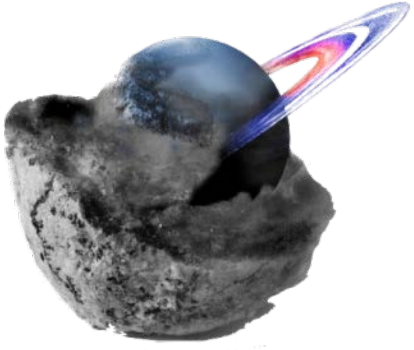
Current TRL	5 Recent flight, 1 channel needs different wavelengths, vastly different radiation, thermal
Heritage	ICON MIGHTI
$ to TRL 6	? Not too much ?
Time to TRL 6	Months?
Notes:	Thermal control, pointing stability, knowledge are drivers



JPL A-Team & Team-X Studies

MOSAIC

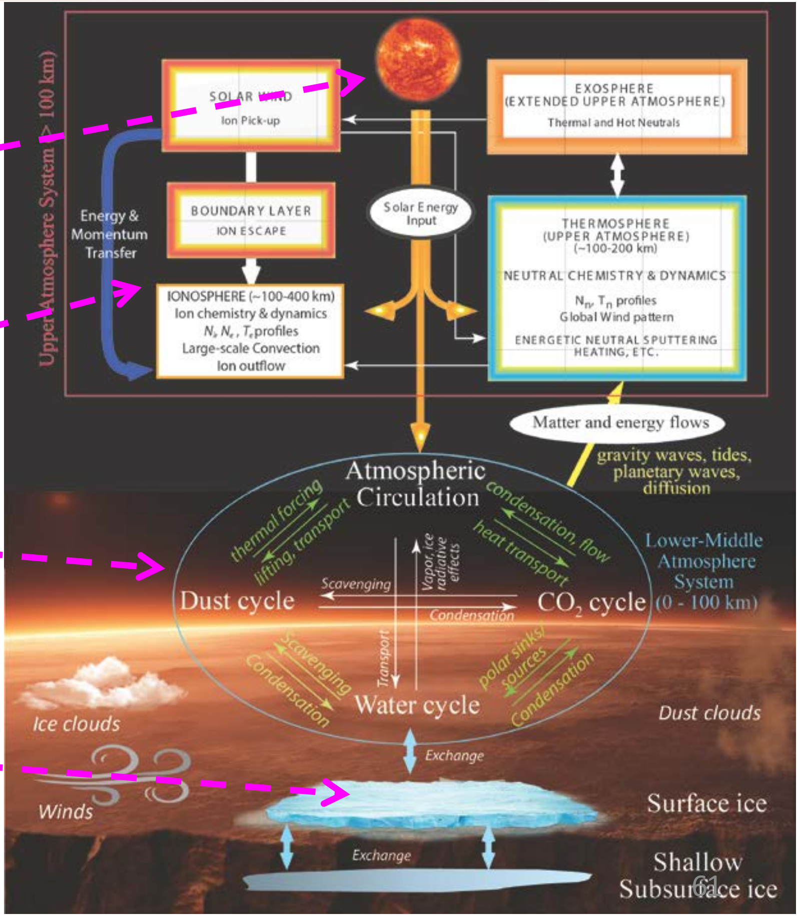
- Examined the study trade space and produced the MOSAIC architecture "building blocks" relevant to the trade space.
- Defined technologies would enable parts of the trade space over the Decadal Survey span (e.g. optical comm).
- Looked at 13 potential architectures, quickly narrowed to four
- Team-Xc and Team-X (in their first ever virtual session) produced point designs by early April 2020.



Backup: MOSAIC Science Slides

MOSAIC Goals & Objectives: Science

<table>
<tr><th>MOSAIC GOALS</th><th colspan="2">Mission Objectives</th></tr>
<tr><td rowspan="5">I. Understand Mars's present day climate processes and their inter-connections, from the sub-surface to the solar wind</td><td colspan="2">I.D Characterize fields and plasma flows in the upstream solar wind and throughout the magnetosphere and upper ionosphere, separating spatial from temporal variability.</td></tr>
<tr><td rowspan="2">I.C: Correlate variability in the thermosphere, ionosphere, and escape rates to:</td><td>Conditions in the lower-middle atmosphere.</td></tr>
<tr><td>The space weather environment</td></tr>
<tr><td colspan="2">I.B: Characterize the structure and dynamics of the Martian lower-middle atmosphere on meso- and global scales, and its geographic, diurnal, and seasonal variability.</td></tr>
<tr><td colspan="2">I.A: Characterize volatile cycling between the subsurface, surface and atmospheric reservoirs.</td></tr>
</table>

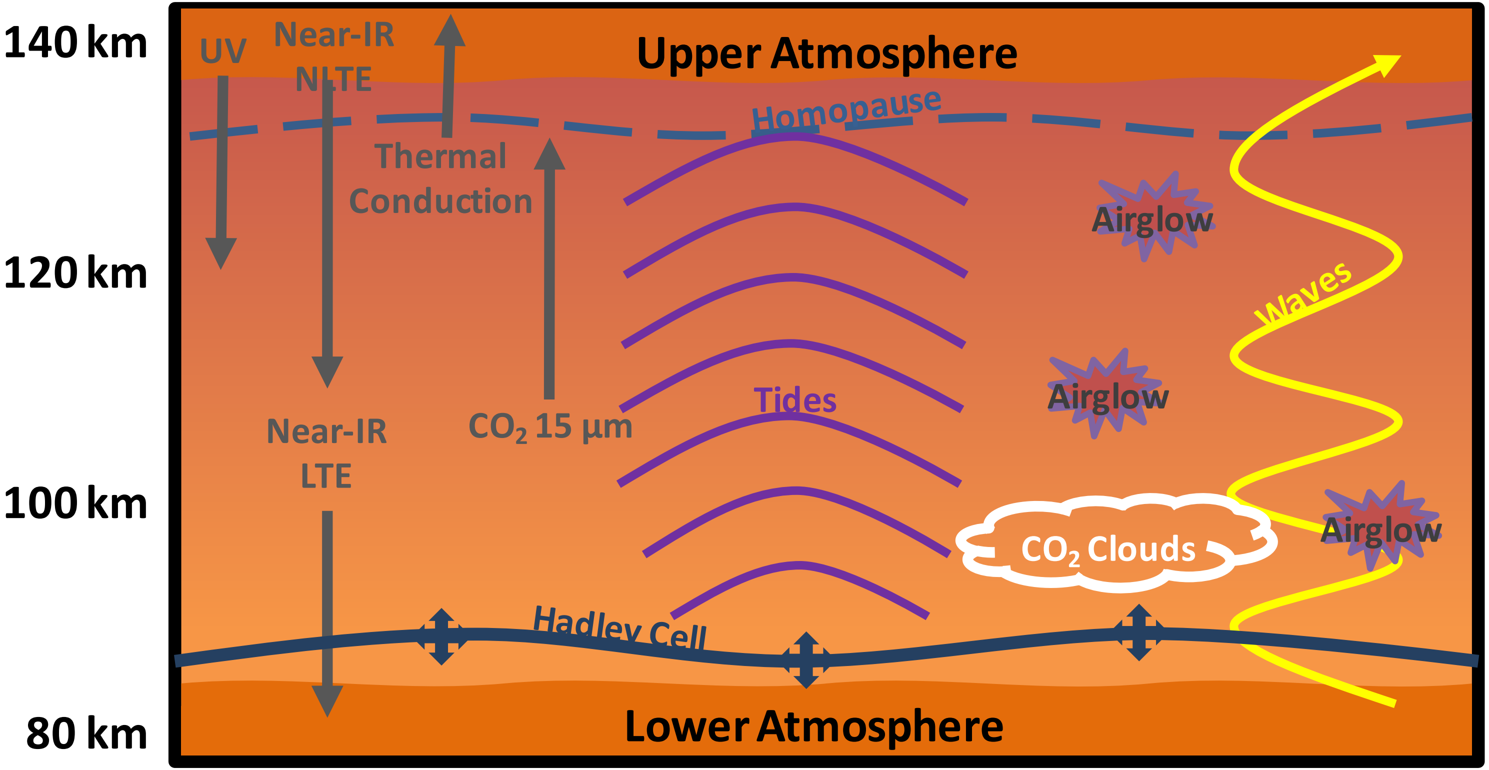


MOSAIC Goals & Objectives

MOSAIC GOALS	Mission Objectives	
I. Understand Mars's present day climate processes and their inter-connections, from the sub-surface to the solar wind	I.A: Characterize volatile cycling between the subsurface, surface and atmospheric reservoirs.	
	I.B: Characterize the structure and dynamics of the Martian lower-middle atmosphere on meso- and global scales, and its geographic, diurnal, and seasonal variability.	
	I.C: Correlate variability in the thermosphere, ionosphere, and escape rates to:	Conditions in the lower-middle atmosphere.
		The space weather environment
	I.D Characterize fields and plasma flows in the upstream solar wind and throughout the magnetosphere and upper ionosphere, separating spatial from temporal variability.	
II. Identify hazards, characterize resources, and demonstrate technologies to enable the Human Exploration of Mars.	II.A: Characterize potentially extractable water ice resources to support in situ resource utilization	
	II.B: Characterize the Mars atmospheric state with sufficient spatial sampling and cadence to allow accurate data assimilation and weather forecasting.	
	II.C: Characterize the Mars ionospheric state and variability sufficiently to determine its likely disruptive effect on communications and positioning	
	II.D: Demonstrate delay-tolerant networking and relay communication between Mars surface, Mars orbit, and Earth.	
	II.E: Demonstrate high-bandwidth deep space communication between Earth and Mars.	

Lower/Upper Atmosphere Connections

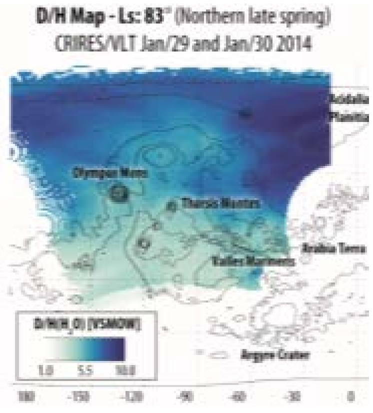
MOSAIC



A. Brecht

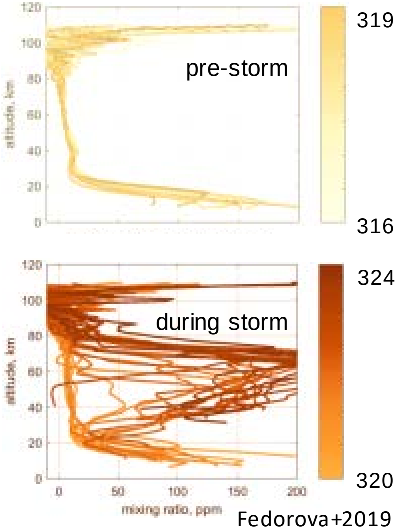
Need comprehensive Lower-Upper atmosphere monitoring

Dust, H_2O, and HDO surface monitoring



Villanueva+2013

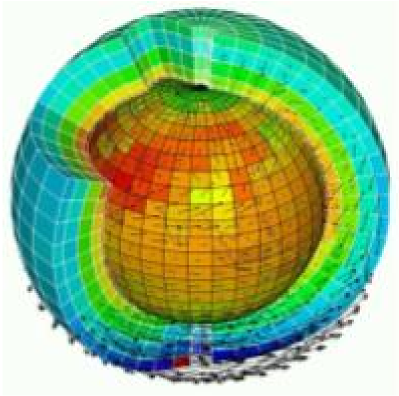
H_2O profiles to ~100km, at all local times



Fedorova+2019

Vis/IR, Microwave, and submm limb and nadir observations

Waves, Tides, and Winds, revealing dynamics



Wind LIDAR, Wind interferometer, Tidal analysis of other datasets

Monitoring of H+O escape

FUV spectroscopy, H absorption cell, Ion Mass Analyzer