National Aeronautics and Space Administration

MoSAIC

Modular Spectrometer for Atmosphere and Ionosphere Characterization

Investigation Overview

Principal Investigator

Mehdi Benna

University of Maryland Baltimore County

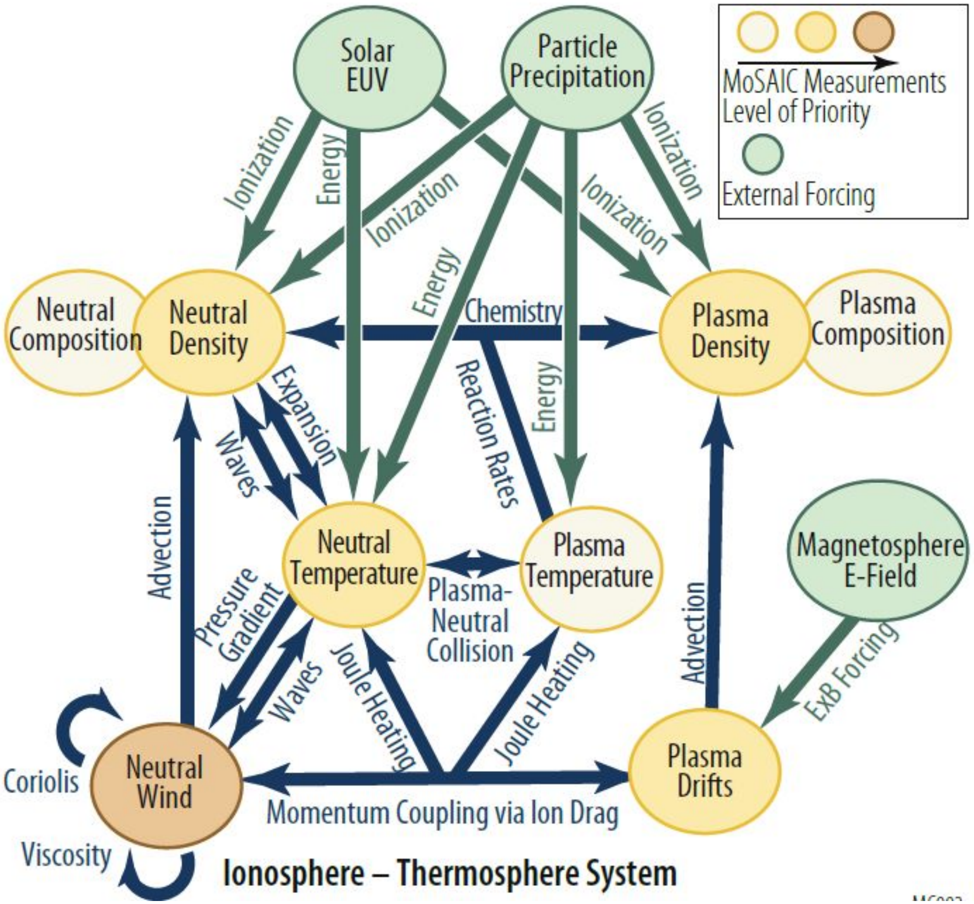
NASA Goddard Space Flight Center

Science Team

Name	Org	MSG Lead	Additional MoSAIC Role	Experience
Mehdi Benna	UMBC/ GSFC	1.1 Co-lead	Leads instrument operation and science coordination	Scientist for MAVEN/NGIMS, LADEE/NMS. PI of M1/SEAL. Co-I of MSL, LADEE, MAVEN. PI of IT sounding rocket DISSIPATION
Mark Conde	U of AK	2.1	Provides relevant ground-based observations. Fosters synergy with ground-based campaigns	PI of multiple ITM sounding rockets, PI of the ground-based Fabry-Perot Interferometer at Poker Flat, AK
Scott England	VA Tech	1.1 Co-lead	Data analysis for atmospheric waves & perturbations. Synergy with ICON/GOLD missions	Project scientist for ICON, Co-I for GOLD, Participating Scientist for MAVEN.
Jeffrey Klenzing	GSFC	1.2	Interpretation of MoSAIC-relevant data from GDC E- and B-field instruments	PI of ITM CubeSat (PetitSat), Co-I of E-field instruments on C/NOFS and multiple IT rockets, ICON mission Scientist
Yuni Lee	UMBC/ GSFC	2.2	Leads data processing and archiving Comparative ITM with Mars and Venus	MAVEN/NGIMS team scientist, PI and Co-I of multiple NASA ROSES ITM modeling grants
Lying Qian	UCAR	2.3	Provides TIE-GCM and WACCM-X modeling	PI and Co-I of multiple NASA ROSES ITM modeling grants, Geospace data analyses and modeling
Aaron Ridley	U of Mich	1.3	Provides GITM modeling	Creator of GITM, CYGNSS Constellation scientist, PI of TIMED/TIDI, GDC STDT Co-Chair.
Marilia Samara	GSFC	2.6	Interpretation of MoSAIC-relevant data from GDC energetic particle instruments	DPI of ITM CubeSat (Dione), PI and Co-I of multiple IT rockets, PI of MOOSE ground-based imagers at Poker Flat, AK

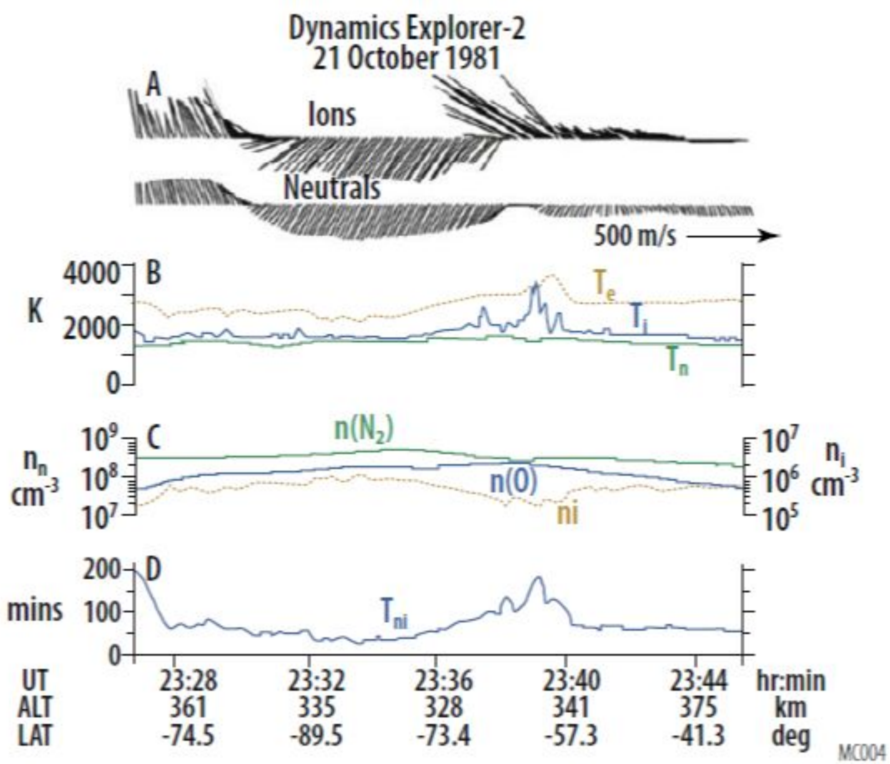
Science Imperative

MoSAIC will investigate all aspects of the coupling of neutral and ionized gases, which is important to the understanding of how the Earth's ITM works, and how **ionized and neutral gases couple and exchange energy** giving rise to a multitude of complex processes.



Measured Parameters

Modular Spectrometer for Atmosphere and Ionosphere

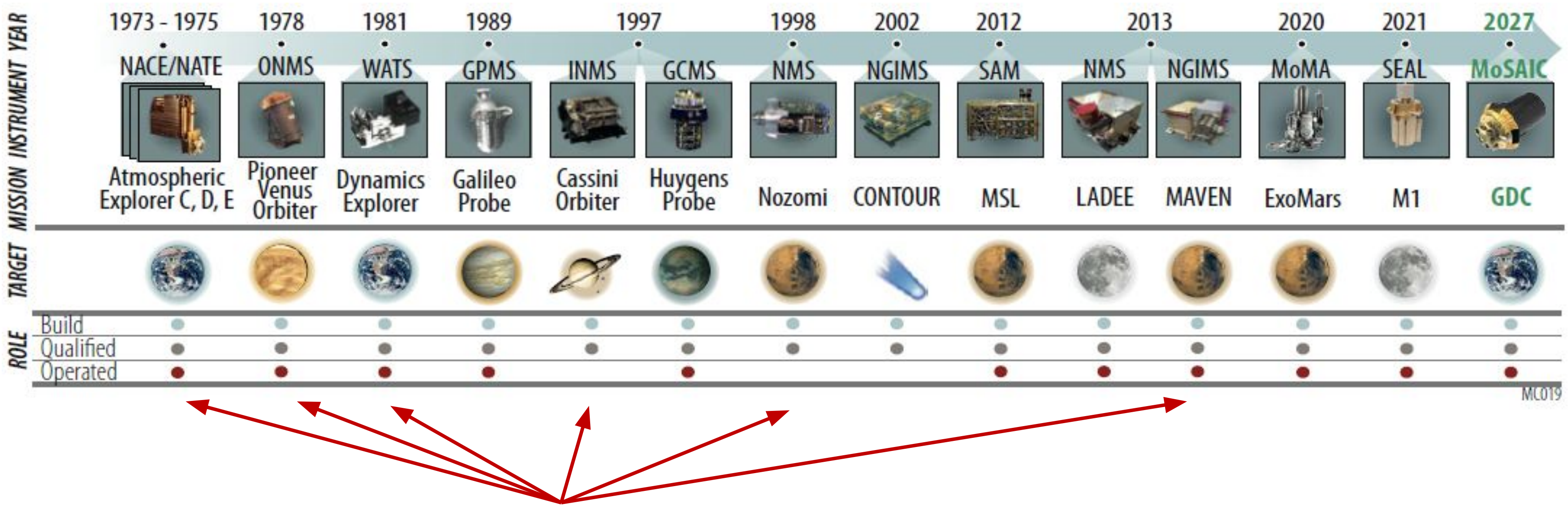


MoSAIC provides multi-point, concurrent high cadence measurements of neutral and ionized gas density, temperature, composition, and motion similar to those provided by DE-2's WATS, FPI, NACS, IDM, and RPA adapted from Killeen et al., 1984].

Measurement Requirements									
Neu. Horiz. Wind	Neu. Vert. Wind	Neu. Density	Neu. Temp	Neu. Comp.	Ion Horiz. Drift	Ion Vert. Drift	Ion Density	Ion Temp	Ion Comp.
Un	Vn	Nn	Tn	Cn	Ui	Vi	Ni	Ti	Ci
5a/5b	5c	6	7	8	1a	1b	2	3	4

Heritage Investigations

MoSAIC targets science questions and replicates techniques deployed on previous Earth and planetary aeronomy missions.



Relevant science heritage

Science Objectives

MoSAI Modular Spectrometer for Atmosphere and Ionosphere

GDC Geospace Dynamics Constellation Exploring Our Connected Atmosphere

MoSAIC distills the GDC Goals and measurement objectives into 7 instrument-centric Goals. These Goals further map into the instrument's required performance detailed in the Science traceability Matrix.

GDC Goals	GDC Objectives	MoSAIC Goals
1. Auroral Processes Understand how the high latitude ionosphere-thermosphere system responds to variable solar wind/magnetosphere forcing.	**1.1** Determine how high-latitude plasma convection and auroral precipitation drive thermospheric neutral winds	**1.1** How does high latitude neutral wind respond to the combined effects of ion drag, particle precipitation, pressure gradients, Coriolis force, and viscosity?
	1.2 Determine how localized, coherent plasma density features arise and evolve.	**1.2** How do storm enhanced densities manifest in the topside ionosphere and how are they influenced by the thermospheric composition, temperature and neutral winds
	1.3 Determine how neutral winds, auroral precipitation, and collisional heating drive high-latitude neutral density structures.	**1.3** How are density enhancements related to vertical upwelling (due to energy deposition) and horizontal advection (driven by neutral wind convergence/divergence).
2. Global effects Understand how internal processes in the global ionosphere-thermosphere system redistribute mass, momentum, and energy.	**2.1** Determine the importance of penetration electric fields and disturbance winds in driving plasma density variations	**2.1** How do perp. and par. ion drifts evolve as disturbance wind progress during storm periods and what is their impact on the evolution ion density as a function of LAT and LT.
	2.2 Identify the processes that create and dissipate propagating structures within the ionosphere and thermosphere.	**2.2** What are the wave energy and momentum contained in TADs and TIDs generated during geomagnetic storm, and how do these vary as they propagate and dissipate.
	2.3 Determine the connections between winds and neutral density/composition variations at mid- and low-latitudes	**2.3** What is the impact of advection (upwelling and horizontal transport) on the density and composition in the thermosphere at high, mid and low latitudes during storms?
	2.6 Determine how hemispheric asymmetries affect the IT system.	**2.6** What are the systematic differences in hemispheric neutral winds, densities, compositions, temperature, and ion drift, density and temperature during quiet conditions

Modular Spectrometer for Atmosphere and Ionosphere

Science Traceability Matrix

GDC GEOSPACE DYNAMICS CONSTELLATION Exploring Our Connected Atmosphere

MoSAIC *Modular Spectrometer for Atmosphere and Ionosphere Characterization*

Science Traceability Matrix

Foldout 1

GDC[a] / MoSAIC INVESTIGATION

Fundamental Themes	STDT Overarching Goals	STDT Objectives	Sub-Objectives	Science Goals[b]	Science Objectives
Local Processes How does the high-latitude IT "engine" operates locally?	OG1	1.1	1.1-1, 1.1-2, 1.1-3	**1.1** Investigate how high-latitude neutral winds respond to the combined effects of ion drag, pressure gradients from particle precipitation and Joule heating, Coriolis force, and viscosity.	Measure neutral winds concurrently with the dominant forcing terms (ion drag, Joule heating, particle precipitation, pressure gradient, and Coriolis force).
		1.2	1.2-2, 1.2-3, 1.2-4	**1.2** Determine how Storm-Enhanced Densities (SEDs) arise and evolve in the ionosphere and how they are influenced by thermospheric density, composition, temperature, and wind.	Identify the presence of an SED and measure co-located neutral density, composition, temperature and wind.
		1.3	1.3-1, 1.3.2, 1.3.3	**1.3** Determine how neutral density enhancements are driven by vertical upwelling and horizontal advection.	Measure vertical and horizontal winds, neutral density, composition, and temperature along the track.
Global Implications How does the high-latitude IT "engine" impact the planet globally?	OG2	2.1	2.1-2, 2.1-3, 2.1-5	**2.1** Determine how field-induced ion drifts and disturbance neutral winds progress during storm periods, and their impact on the global evolution of plasma density.	Measure the temporal evolution of disturbance winds (perturbation relative to quiet time) and ion drifts at mid/low latitude along with changes in local ion density.
		2.2	2.2-1, 2.2-2, 2.2-3, 2.2-4, 2.2-5	**2,2** Measure the wave energy and momentum of TADs and TIDs generated during geomagnetic storm and determine how they vary as they propagate and dissipate.	Measure horizontal plasma drift, density, temperature, and composition to characterize TIDs, and horizontal neutral wind, density, temperature and composition to characterize TADs.
		2.3	2.3-1, 2.3-2, 2.3-3	**2.3** Investigate the impact of advection (upwelling and horizontal transport) on the density and composition of the thermosphere at high-, mid- and low-latitudes.	Measure the evolution of neutral density, composition, and wind at high-, mid- and low-latitude during storm events.
		2.6	2.6-1, 2.6-2, 2.6-3, 2.6-4	**2.6** Determine the systematic hemispheric differences in thermospheric/ionospheric winds/drifts, densities, compositions, and temperatures.	Measure long-term trends (seasonal variations) of neutral and ion wind/drift, density, composition, and temperature during quiet geomagnetic conditions.

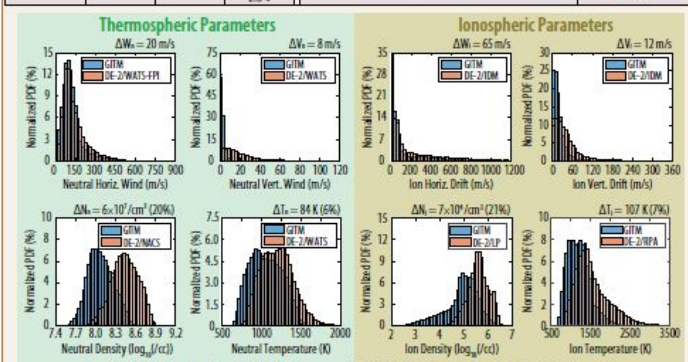
Measurement Requirements[c,d,e]

STDT Objectives	Neu. Horiz. Wind	Neu. Vert. Wind	Neu. Density	Neu. Temp	Neu. Comp.	Ion Horiz. Drift	Ion Vert. Drift	Ion Density	Ion Temp	Ion Comp.
	W_n	V_n	N_n	T_n	C_n	W_i	V_i	N_i	T_i	C_i
	5a/5b	5c	6	7	8	1a	1b	2	3	4
1.1	P	P	P	P	S	P	P	P	S	S
1.2	P	S	P	P	P	S	S	P		S
1.3	P	S	P	P	P	P	P	P	S	
2.1	P				S	P	P	P		
2.2	P		P	P	P	P		P	P	P
2.3	P	P	P	P	P			S	S	
2.6	P	P	P	P	P	P	P	P	P	P

MISSION REQUIREMENTS

STDT Objectives	Relevant Mission Phases	Relevant Geomagnetic Conditions	Requited Supporting Information
1.1	Primary: 1a to 2b Secondary: 3a, 3b	Quiet (baseline) Active (disturbance)	Concurrent measurements of energetic electron flux provide estimate of heating by particle precipitation.
1.2	Primary: 1b, 2a Secondary: 2b	Active	Concurrent ground-based TEC measurements provide the global context for the SED.
1.3	Primary: 2b to 3c Secondary: 2a	Active	Concurrent measurements of energetic electron flux provide estimates of heating by particle precipitation.
2.1	Primary: 2a, 3b Secondary: 3c	Quiet (baseline) Active (disturbance)	Concurrent auroral precipitation and/or FAC data inform on the storm strength. Concurrent ground-based TEC observations localize the ion peak.
2.2	Primary: 2a Secondary: 1b	Active	
2.3	Primary: 2a, 2b Secondary: 3a to 3c	Quiet (baseline) Active (disturbance)	Concurrent ground-based high-latitude TEC measurements provide the global context of geomagnetic forcing.
2.6	Primary: 3b Secondary: all	Quiet	

		W_n	V_n	N_n	T_n	C_n	W_i	V_i	N_i	T_i	C_i
MoSAIC Requirements	Range	±1700 m/s	±250 m/s	$10^7 - 10^{9.5}$ /cm³	250-4000 K	1 - 40 amu	±2400 m/s	±800 m/s	$10^2 - 10^7$ /cm³	250-8000 K	1 - 32 amu
	Accuracy	20 m/s	8 m/s	20%	6%	20%	65 m/s	12 m/s	21%	7%	20%
	Precision	10 m/s	4 m/s	10%	3%	10%	32 m/s	6 m/s	10%	3%	10%
	Cadence	2 s	2 s	2 s	2 s	2 s	2 s	2 s	2 s	2 s	2 s
MoSAIC Performance	Range	±4200 m/s	± 3000 m/s	$10^7 - 7\times10^{12}$ /cm³	100-10,000 K	1 - 150 amu	±4200 m/s	± 3000 m/s	$10^{-2} - 10^9$ /cm³	100-10,000 K	1 - 150 amu
	Accuracy	4.5 m/s	3.5 m/s	10%	2%	1%	4.5 m/s	3.5 m/s	10%	2%	1%
	Precision	4.5 m/s	3.5 m/s	1%	2%	1%	4.5 m/s	3.5 m/s	1%	2%	1%
	Cadence[f]	1 - 2 s	1 - 2 s	1 - 2 s	1 - 2 s	1 - 2 s	1 - 2 s	1 - 2 s	1 - 2 s	1 - 2 s	1 - 2 s
PEA Expected Performance	Range	±1500 m/s	± 150 m/s	$10^7 - 10^{10}$ /cm³	400 - 2000 K	1 - 40 amu	±5000 m/s	±2000 m/s	$10^2 - 10^7$ /cm³	600 - 1500 K	1 - 32 amu
	Accuracy	20 m/s	20 m/s	10%	10%	5%	20 m/s	20 m/s	10%	10%	1%
	Precision	10 m/s	10 m/s	2%	2%	5%	20 m/s	20 m/s	1%	5%	1%
	Cadence	3 s	3 s	3 s	3 s	3 s	1 s	1 s	1 s	1 s	1 s



Statistical Analysis of DE-2 Data and GITM Flythough of GDC Mission [g]

Notes

(a) Derived from GDC STDT report and PIP.

(b) Threshold investigation provides MSG 1.1 and 2.1 (§D.3).

(c) Each paramter is given with name, abrev., and priority as listed in PEA.

(d) Horizontal wind/drift combines along-track velocity and a component of across-track velocity.

(e) Vertical drift is along B-field at high-latitudes.

(f) Cadence = 2 s using baseline sequence. Becomes 1 s using ion/neutral-only sequence (§E.2.2).

(g) See §D.2.2 for more details.

Legend

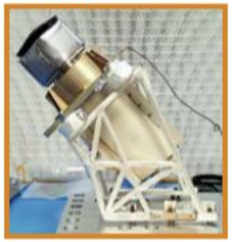
- P — Primary Parameter
- S — Supporting Parameter

Targeted Measurement Performance

	Neu. Horiz. Wind	Neu. Vert. Wind	Neu. Density	Neu. Temp	Neu. Comp.	Ion Horiz. Drift	Ion Vert. Drift	Ion Density	Ion Temp	Ion Comp.
	W_n	V_n	N_n	T_n	C_n	W_i	V_i	N_i	T_i	C_i
	5a/5b	5c	6	7	8	1a	1b	2	3	4
Range	±4200 m/s	± 3000 m/s	10^7–7×10^{12} /cm^3	100–10,000 K	1 – 150 amu	±4200 m/s	± 3000 m/s	10^{-2} – 10^9 /cm^3	100–10,000 K	1 – 150 amu
Accuracy	4.5 m/s	3.5 m/s	10%	2%	1%	4.5 m/s	3.5 m/s	10%	2%	1%
Precision	4.5 m/s	3.5 m/s	1%	2%	1%	4.5 m/s	3.5 m/s	1%	2%	1%
Cadence[(f)]	1 - 2 s	1 - 2 s	1 - 2 s	1 - 2 s	1 - 2 s	1 - 2 s	1 - 2 s	1 - 2 s	1 - 2 s	1 - 2 s

Instrument Concept

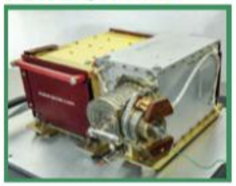
M1/SEAL



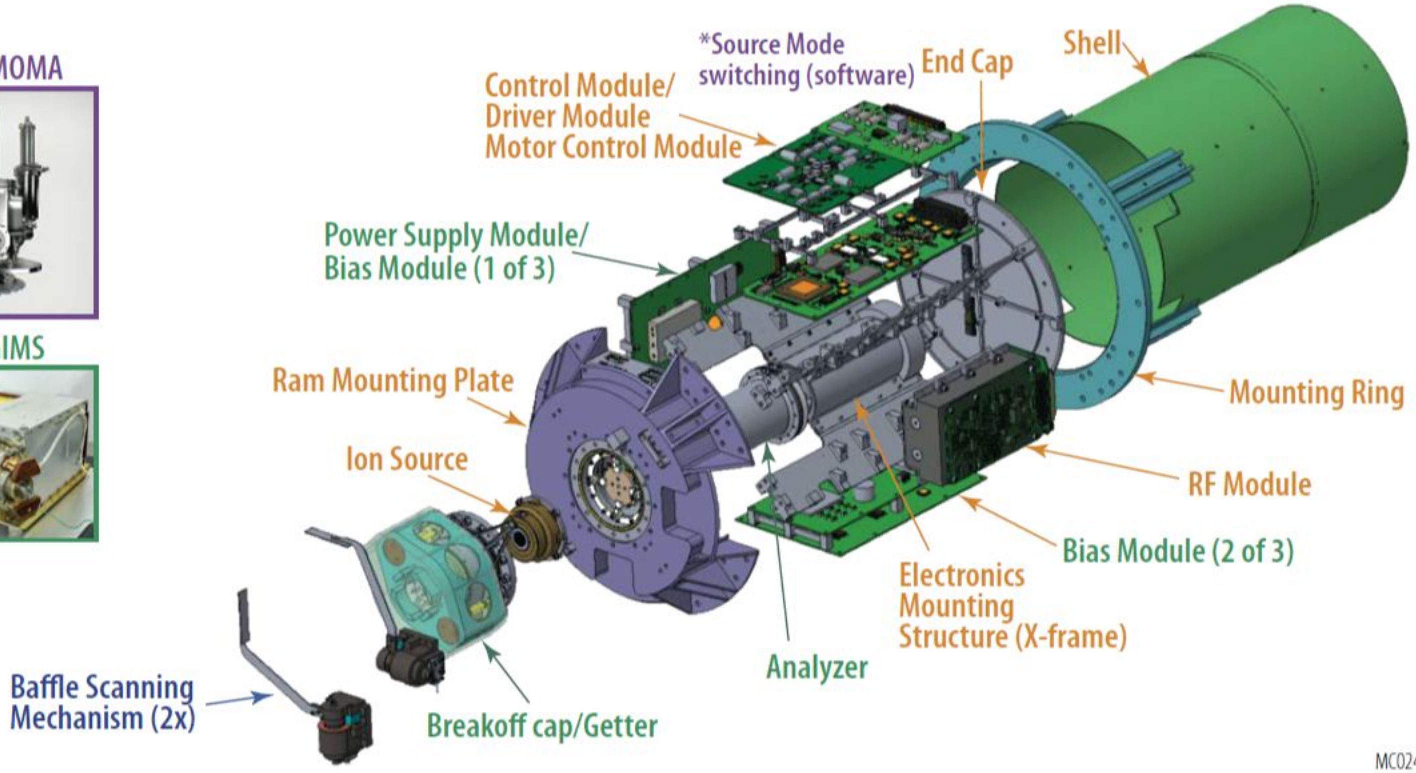
ExoMars/MOMA

Nozomi/NMS

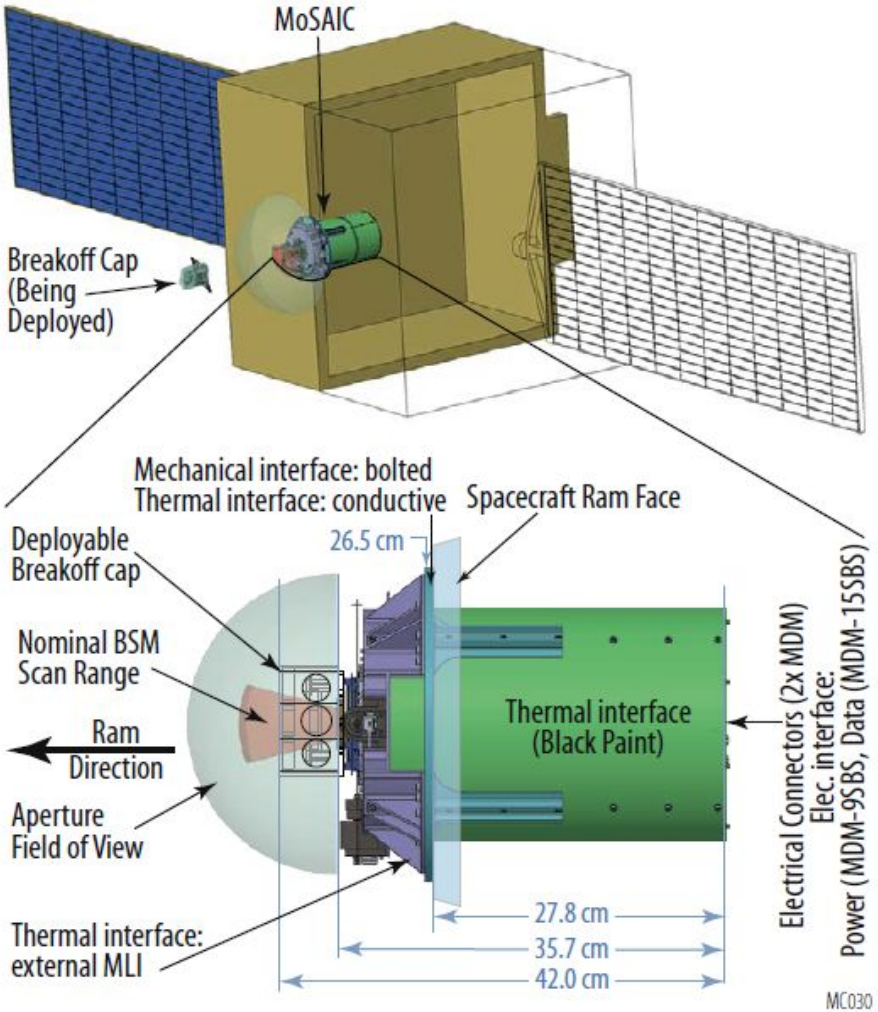
MAVEN/NGIMS



DE-2/WATS



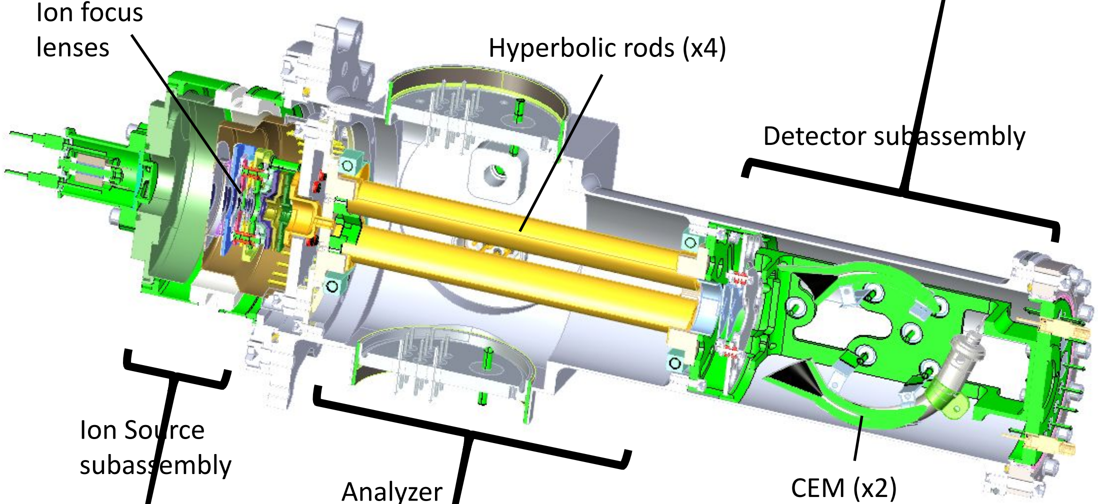
Accommodation Requirements



Instrument Accommodation Summary	
Requirement	**Value**
Pointing Direction	Boresight toward ram
FoV*	2π str
Pointing Precision*	2°
Pointing Knowledge*	0.02°
Mass	7.26 kg (CBE)
Peak Power	27.7 W (CBE)
Average Power	22.5 W (CBE)
Envelope	42.0 x 26.5 x 26.5 cm^3
Mounting Area, Ram Face	551.5 cm^2
Electrical Interface	28 V unreg. – RS-422
Data Rate	5 kbps (CBE)
Data Volume	27.6 Mb/orbit (CBE)

* during science operations

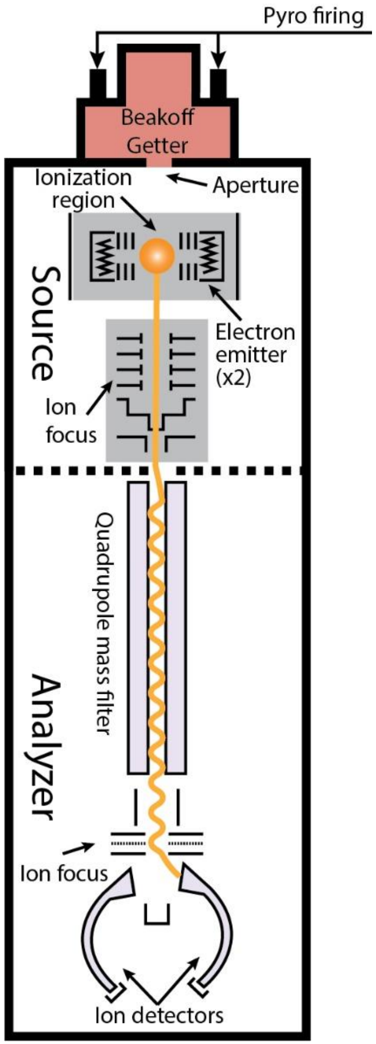
The Quadrupole Sensor (1/2)



Most MoSAIC QMS sensor elements are build-to print copies from previous sensors designed, built, and successfully operated on the Nozomi/NMS, LADEE/NMS, MAVEN/NGIMS, and Peregrine M1/Surface and Exosphere Alterations by Landers (SEAL) investigations.

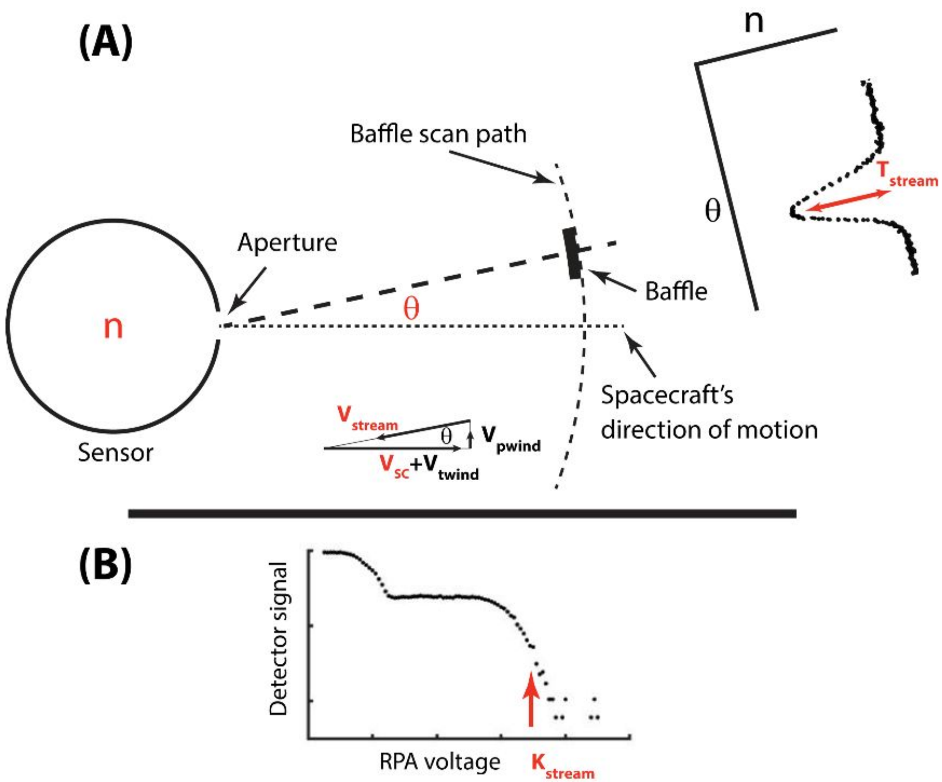
The Quadrupole Sensor (2/2)

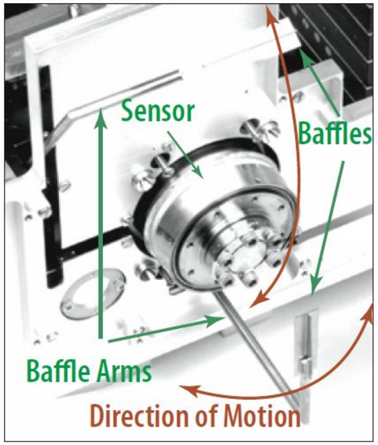
- **Neutral Gas and Ion Sampling:** Electrically selective:
  - **Closed Source:** thermalized gas (S/C ram pressure enhancement)
  - **Open Source:** molecular beaming (number flux measurement)
  - **Ions:** thermal and suprathermal (< 30 eV)
- **Ion Source:** Electron beam ionization (Redundant)
- **Electron Energy:** 75 eV
- **Mass Range:** 1 to 150 Da (H^+ to Xe^+)
- **Quadrupole Radio Frequencies:** 3
- **Resolution/Crosstalk:** 10^{-6} for adjacent masses
- **Detector System:**
  - Redundant pulse counting multipliers
  - Variable integration period 10 -250 ms
- **Scan Modes:**
  - Programmed mass vector
  - Survey (scan in 1/10 or 1 amu steps)
  - Energy scans (retarding potential analyser)
- **Electrical Interfaces:** RS-422 / 28V
- **Deployment Mechanism:** jettisoned metal ceramic breakoff cap
- **Internal BA Pressure Gauge:** 10^{-8} to 10^{-3} mbar
- **Inheritance:** Nozomi/NMS, MAVEN/NGIMS, SEAL



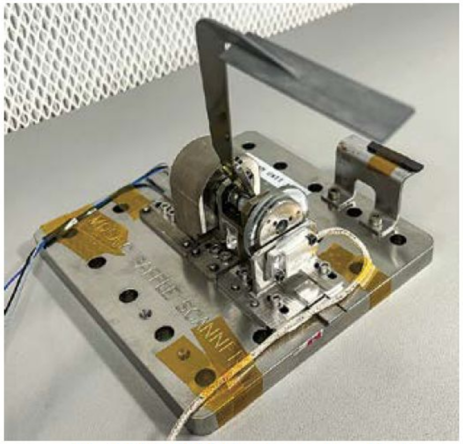
The Baffle Scanning Mechanism (1/2)

MoSAIC improves on the baffle technique used on DE2 to provide three-dimensional measurements of motion and temperature of both neutral gas and cold plasma.

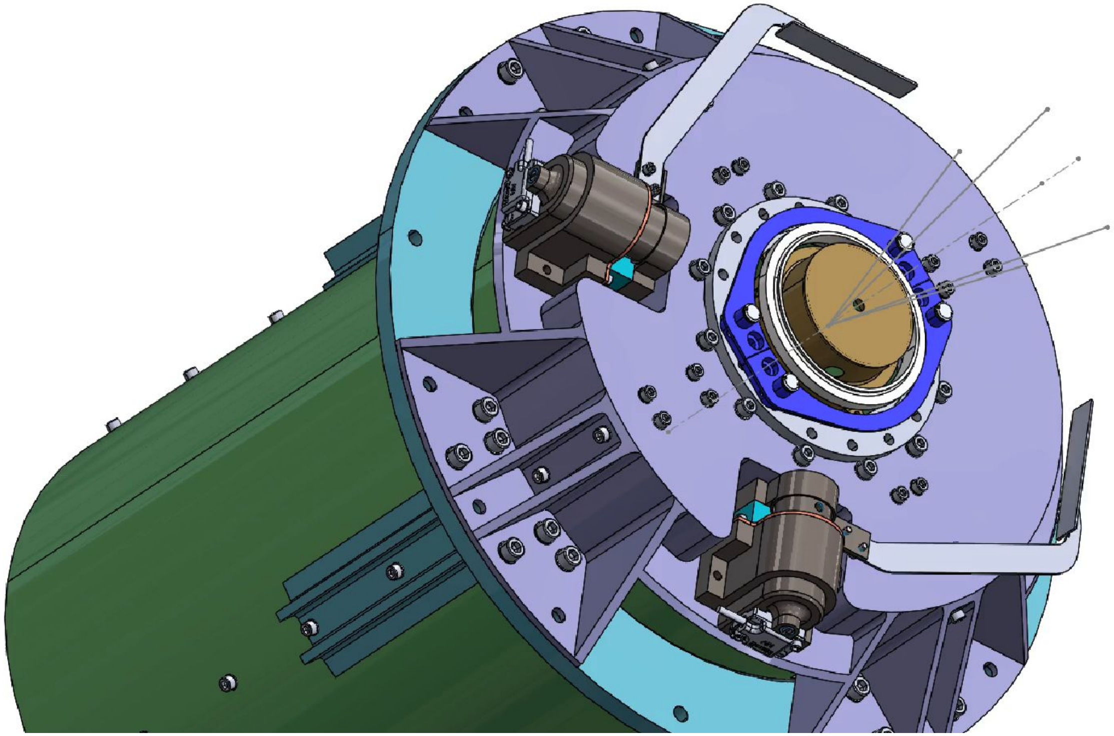




DE2-WATS BSM

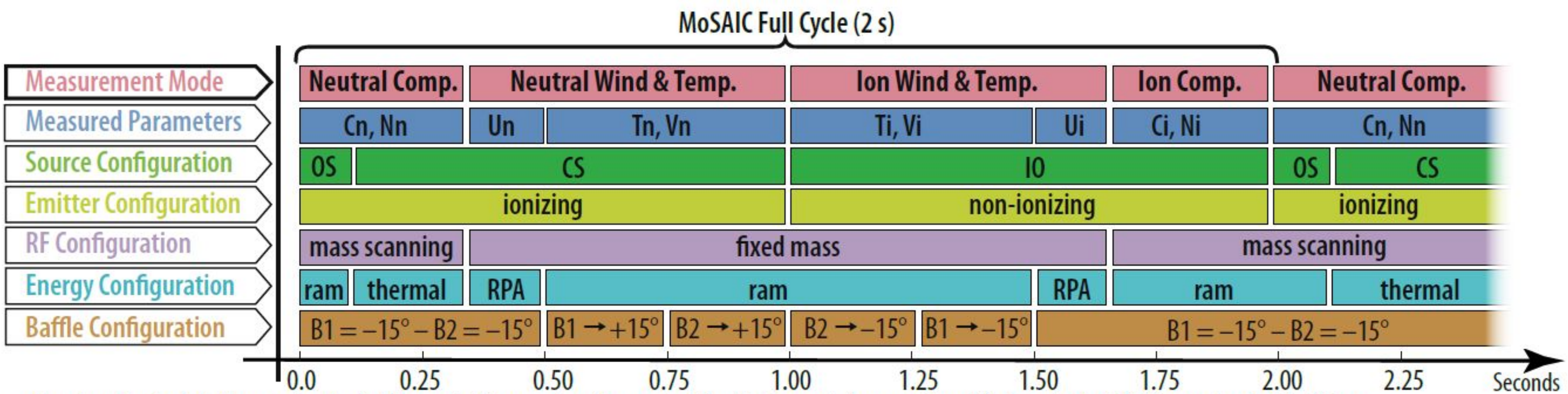

MoSAIC BSM Engineering Unit (used in lifetime testing)

The Baffle Scanning Mechanism (2/2)



Concept of Operation

During the 2-second baseline cycle, **MoSAIC's** source, baffles, and analyzer settings are rapidly reconfigured by the electronics to acquire measurements of the desired parameter (ion or neutral, density, composition, temperature, motion).



- **Un**: along-track wind, **Vn**: cross-track wind, **Tn**: neutral temperature, **Nn**: neutral density, **Cn**: neutral composition, **Ui**: along-track drift, **Vi**: cross-track drift, **Ti**: ion temperature, **Ni**: ion density, **Ci**: ion composition.
- **OS**: open source mode, **CS**: closed source mode, **IO**: ion mode

MC026

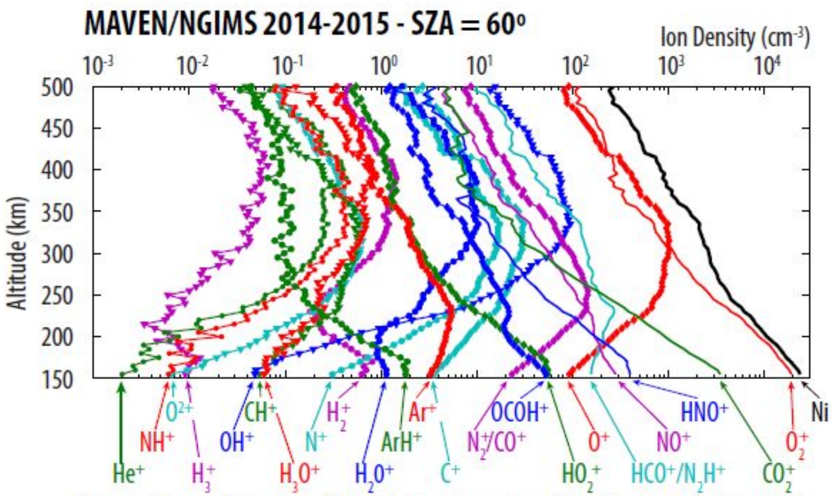
Data Plan

MoSAIC leverages tools, expertise, and experience successfully demonstrated through processing and archiving Mars thermospheric data collected by MAVEN/NGIMS.

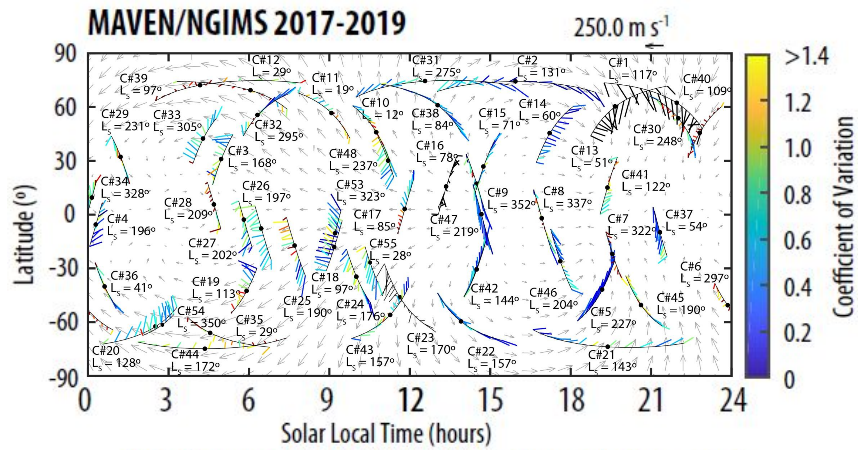
Data Level	Description	Archived at SPDF
0	Binary packets as produced by MoSAIC.	Yes
1A	Packets separated by telemetry channel (housekeeping, science, instrument log) and converted to CDF format.	Yes
1B	Calibrated Data Record: (1) Time-stamped spectra (counts per unit mass) separated by mode (ion or neutral) and source (closed or open) and corrected for deadtime and background. Product includes relevant ephemeris (e.g., sensor boresight pointing, altitude, and spacecraft velocity). (2) Time-stamped BSM scans (counts per BSM position) separated by mode (ion or neutral) and corrected for deadtime and background. (3) Time-stamped RPA scans (counts per unit energy) separated by mode (ion or neutral) and corrected for deadtime and background. All files are in CDF format.	Yes
2	Derived Data Record: (1) Single neutral and ion species abundance vs time. (2) Along-track and cross-track components of wind and drift vs time. (3) Neutral and ion temperature vs time. All products include altitude, local time, latitude, and longitude information. All files include measurement uncertainties and are in CDF format.	Yes
Real-time (produced by SOC)	Quick-look data generated from processing the real-time telemetry and provided at a cadence of once every 10 s: (1) abundance vs time of N_2, O, and O_2^+. (2) Along-track and cross-track wind and drift velocities vs time. (3) Neutral and ion temperature vs time. All files are in ASCII format.	No (archived by SOC)

Modular Spectrometer for Atmosphere and Ionosphere

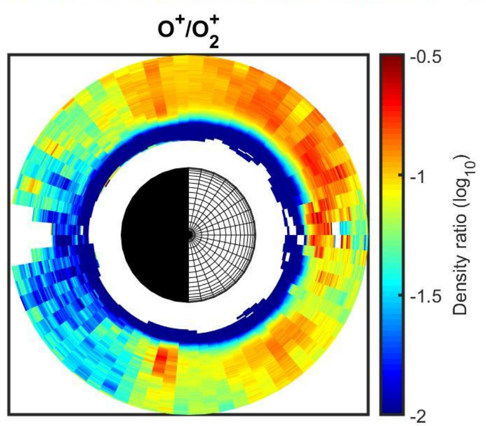
Example of Science Products

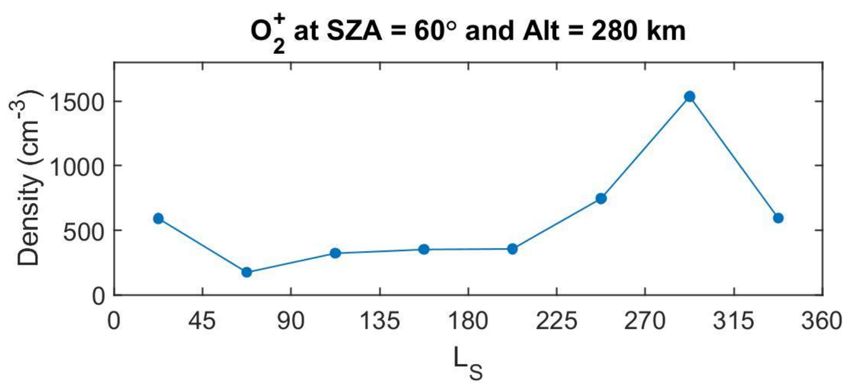


Composition and structure of the Martian ionopshere (from Benna et al., GRL, 2015)



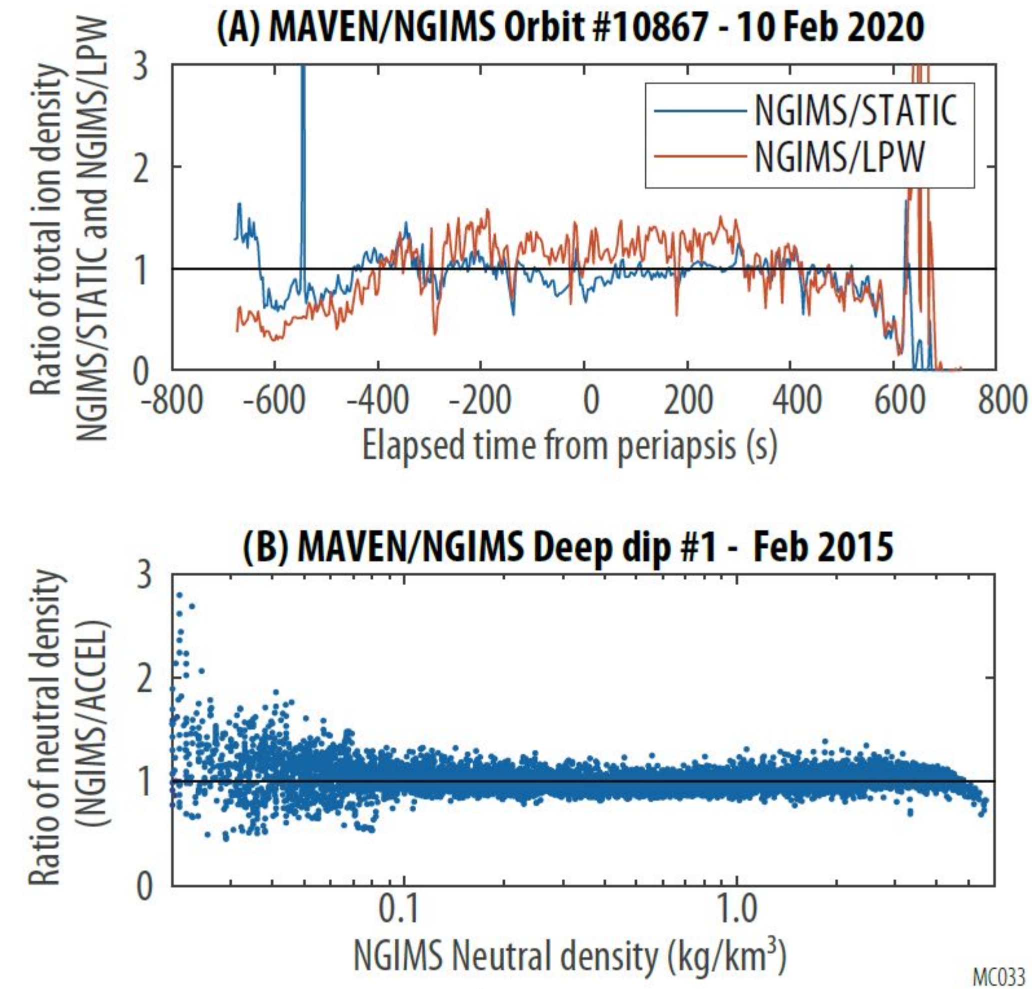
Global thermospheric circulation at Mars (Benna et al., Science, 2019)





Modular Spectrometer for Atmosphere and Ionosphere

Cross Calibration with other relevant GDC investigations



Current Status

- Technical team is fully staffed and up and running
- Partner institution on pre-contract agreements
- Issued RFP's to partner institutions, awaiting proposals;
- Post-selection cost and schedule reassessment completed
- Formal transfer of ETU sensor parts from legacy missions completed
- Continue internal vetting of subsystem parts lists in preparation for parts procurements.
- Long Lead Procurement request sent to HQ for approval
- Start sensor fit-checks of mechanical parts
- Continue progress towards ISRR